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SITE ASSESSMENT AND CORRECTIVE ACTION WORKPLAN

GOLDEN GATE PETROLEUM
421 23RD AVENUE
OAKLAND, CALIFONRIA

Bonkowski and Associates, Inc.

3650 Mount Diablo Boulevard, Suite 200

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16 November 1998

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November 16, 1998
Project L98174.cap

Harvey Brook

Mr. William Martin Retired
Golden Gate Petroleum
1001 Galaxy Way, Suite 308
Concord, California 94520

Subject: Site Assessment and Corrective
Action Workplan
421 23rd Avenue
Oakland, California

Dear Mr. Martin:

The enclosed Site Assessment and Corrective Action Workplan was prepared on behalf of Golden Gate Petroleum by Bonkowski & Associates, Inc. The plan is prepared for submittal to the Alameda County Health Care Services Agency, Division of Environmental Protection in response to their letter directive dated August 21, 1998.

We look forward to meeting with you in the near future to discuss the implementation of the Workplan and the overall project with the Alameda County Health Care Services Agency and the Cleanup Fund. If you have any questions, please contact Cynthia Dittmar or Michael S. Bonkowski at (~~510~~) 283-9042.
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Sincerely yours,
BONKOWSKI & ASSOCIATES, INC.

Michael S. Bonkowski, CEG 1329
Senior Managing Principal

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SITE ASSESSMENT AND CORRECTIVE ACTION WORKPLAN GOLDEN GATE PETROLEUM

421 23rd Avenue
Oakland, California

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1.0 INTRODUCTION

The Alameda County Department of Health Care Services Agency, Division of Environmental Protection (ACDHCS) is overseeing the cleanup of an unauthorized release of petroleum fuel from an underground storage tank system at the Golden Gate Petroleum Oakland Cardlock, located at 421 23rd Avenue, in Oakland, California (Figure 1).

California underground storage tank regulations (23 CCR 2725) require that Golden Gate Petroleum prepare a Corrective Action Plan which presents, with supporting rationale, a cost-effective plan to cleanup the hydrocarbon residues in soil and groundwater at the site. Bonkowski & Associates, Inc. has prepared this Site Assessment and Corrective Action Workplan on behalf of Golden Gate Petroleum in accordance with a directive dated 21 August 1998 from Mr. Barney Chan of the ACDHCS and to meet this state underground storage tank regulatory requirement.

Since the release was discovered by Golden Gate Petroleum, Interim Remedial Measures (IRM) activities at the site have removed a significant portion of the source soils at the site. Using the data collected during the IRM activities and to be collected during the site assessment, alternative cleanup technologies were compared to identify the most cost-effective remedy to control and recover released petroleum fuel hydrocarbons. The selected cleanup plan consists of pumping and treating groundwater from an existing collector trench, and verification of cleanup effectiveness through groundwater monitoring. This treatment remedy was selected as the most cost-effective for this site where shallow groundwater occurs primarily in alluvial bay margin soils. Verification monitoring is planned for two years following achievement of cleanup standards to protect existing and potential beneficial uses of groundwater.

1.1 Purpose of the Corrective Action Plan

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The Corrective Action Plan is required by California State regulations to present the proposed cleanup plan together with the proposed cleanup standards and cleanup effectiveness monitoring plan. Golden Gate Petroleum is required by these regulations to select the most "cost-effective" remedy for the site. "Cost-effective" is defined as "actions that achieve similar or greater water quality benefits at an equal or lesser cost than other corrective actions" (23 CCR 2700). The choice of cleanup method must be supported by site characterization data and the demonstrated effectiveness of the cleanup method. To select the most "cost-effective" plan, Bonkowski & Associates, Inc. considered: (1) the properties of the hydrocarbons including their toxicity, persistence, physical and chemical properties, (2) the magnitude and extent of subsurface contamination, (3) the regulatory action levels for odor and taste thresholds, maximum contaminant levels, and (4) the State non-degradation policies regarding groundwater quality and pollution.

A principal part of the Corrective Action Plan is the screening of remedial alternatives. The screening process is a comparison of the advantages and disadvantages of using available remedial action alternatives to mitigate hydrocarbons at this site. The screening process considers remediation technologies which have been used at other hydrocarbon contaminated sites. Selection of the recommended treatment alternative involved assessing candidate technologies, combining technologies to form remedial alternatives, and considering the costs and benefits of potential alternatives.

1.2 Report Organization

The Corrective Action Plan has been organized into eight sections. Section 1.0 contains introductory material. Section 2.0 describes the site background. Section 3.0 outlines the planned investigative work for the site. Section 4.0 outlines the remedial objectives for the site. Section 5.0 screens remedial technologies. Section 6.0 compares remedial alternatives. Section 7.0 describes the recommended remedial alternative. Section 8.0 describes the project schedule. Section 9.0 lists the referenced reports and Workplans prepared following the hydrocarbon release discovery.

1.3 Project Team

This Site Assessment Workplan and Corrective Action Plan was prepared by Bonkowski & Associates, Inc. The key Bonkowski & Associates, Inc. staff involved with this effort included Mr. Michael S. Bonkowski, CEG, Mr. Timothy Tatum, Ms. Cynthia Dittmar, EIT, and Mr. Peter Holland.

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2.0 SITE DESCRIPTION

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Golden Gate Petroleum Oakland Cardlock occupies an irregular shaped parcel that is bordered by 23rd Avenue on the east, Kennedy Avenue on the south and west, and commercial property to the north. Five single wall underground storage tanks, and associated piping and dispenser islands were formerly located at the site (Figure 2). The five tanks were buried side by side in a cluster, and used to store premium unleaded and regular unleaded gasolines, and diesel fuel for motor vehicle use. As described below, the tanks, piping and dispenser islands were removed in August, 1998. The underground tanks were replaced with two 20,000 gallon tanks in the same tank cavity. The dispenser islands were replaced at their former locations (Figure 3).

2.1 Background

The station has been in operation since 1976. On 11 August 1998 Golden Gate Petroleum initiated work to remove the underground storage tanks, product lines and dispenser islands to comply with 40 CFR Code of Federal Regulations, Part 280. The removal of underground storage tanks and hydrocarbon contaminated soil and groundwater at the Golden Gate Petroleum Oakland Cardlock was conducted by Bonkowski & Associates, in accordance with the "Supplemental IRM Workplan" (Bonkowski & Associates, Inc., August 18, 1998) which was approved by the ACDHCS on 21 August 1998. The initial field work was directed by City of Oakland Fire Inspector LeRoy Griffin on 14 August 1998.

Five original underground storage tanks, dispenser islands, and product lines were removed in August 1998. The underground storage tanks were replaced with two 20,000 gallon double wall fiberglass tanks. A collector trench was placed near the new tanks in the existing tank cavity (Figure 3), which was the backfilled with pea gravel. Approximately 1,300 cubic yards of the surrounding hydrocarbon impacted soil was excavated and removed. Forty-nine soil samples and one groundwater sample were collected from the tank cavity and tested for TPHG, TPHD, BTEX and MTBE, by EPA methods 8260, 8015 and 8020M. The sample locations are shown in Figure 4. Approximately 28,000 gallons of groundwater and separate phase hydrocarbons were pumped from the open tank cavity into Baker Tanks. A portion of this groundwater was discharged to the East Bay Municipal Utilities District Treatment Works and a portion was offhauled for disposal of by Clearwater Environmental Management, Inc.

2.2 Hydrogeologic Setting

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In general, subsurface soils consist primarily of sandy silts to silty sands from the ground surface to a depth of 15 feet. The depth to groundwater is approximately 11 feet. The direction of groundwater flow, although influenced by tidal fluctuations, is anticipated to be generally to the southwest toward the Oakland estuary.

2.3 Groundwater Supply and Beneficial Uses

The Bay Area Regional Water Quality Control Plan "Basin Plan" dated December 1986 has designated the beneficial use of groundwater at this location as municipal, industrial process water, industrial service supply, and agricultural supply.

2.4 Surface Water Supply and Beneficial Uses

The site is situated approximately 700 feet from the Tidal Canal to the San Leandro Bay. The Bay Area Regional Water Quality Control Plan "Basin Plan" dated December 1986 has designated the beneficial use of surface coastal waters at this location as contact and non-contact recreation, industrial service supply, navigation, marine habitat, shell-fish harvesting, ocean, commercial and sport fishing, areas of special biological significance, and preservation of rare and endangered species.

2.5 Soil Quality

Hydrocarbons have been detected in soil at the site, in the vicinity of the underground storage tanks, the product dispenser islands, and supply lines. TPHG, TPHD, BTEX and MTBE have all been reported at concentrations that exceed California Cleanup Screening Levels (CSLs) and/or EPA Preliminary Remediation Goals (PRGs). Soil chemical test results, from samples collected during the IRM activities are summarized in Appendix A, Table A1. The CSLs and PRGs for hydrocarbon concentration are summarized below.

Y146 Clean-up Criteria
ASTM
DS 64

Source?

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PARAMETER	CALIFORNIA CLEANUP SCREENING LEVELS		PRELIMINARY REMEDIATION GOALS	
Petroleum Fuel <u>Hydrocarbons</u>	Non drinking water < 40' below surface (ppmw)	100x MCL ↓ ppm	Industrial Water (ppmw)	
Benzene	0.1		3.2	soil ind
Ethylbenzene	68	1000	690	
Toluene	10		2,800	soil ind
Total Xylenes	175	100x	--	
MTBE	--		3,400	
TPH (C8-C12)	1,000	?	--	
TPH (C13-C22)	10,000		--	
TPH (>C23)	15,000		--	

2.6 Groundwater Quality

Groundwater samples collected from beneath the site during the implementation of the IRM activities contained dissolved phase petroleum fuel hydrocarbons, including benzene, methyl tertiary butyl ether (MTBE) and tertiary amyl methyl ether (TAME). One groundwater sample collected from Baker Tanks which stored groundwater until it could be offhauled and discharged also contained 26 ug/l lead. These groundwater chemical test results are summarized in Appendix A, Table A2 and A3.

3.0 PLANNED SITE WORK

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The section describes the technical approach that will be used to perform a site assessment and implement corrective actions at the site. The recommended task were prepared based upon our understanding of California underground storage tank regulations, the directive issued by the ACDHCS, and the use of the property as a card lock facility for the retail sale of gasoline. Specific features of the work include: 1) the use of a geoprobe with continuous sampling techniques, 2) the installation of monitor wells, 3) subsurface hydrostratigraphic analysis, 4) and the operation of a groundwater extraction and treatment system at the site.

Task 1: Evaluate Extent of Soil and Groundwater Contamination

Eight Geoprobe test holes (GP-1 - GP-8) will be at the locations shown on Figure 5. It is anticipated that groundwater will be encountered at a depth of approximately 11 feet at most geoprobe locations, and thus the geoprobes will be advanced to a depth of 20 feet, to penetrate 10 feet into the groundwater table. The survey will be conducted with a truck mounted Geoprobe 5400 rig.

Soil samples will be collected continuously to the total depth of each location. The samples will be collected by advancing a four-foot rigid clear plastic tube through the Geoprobe sampler into the undisturbed soil. This tube, when extracted from the boring, cut in half and divided into equal sections in the field. A Bonkowski & Associates field engineer will log the soil using ASTM Method D-2488, Description of Soils (Visual-Manual Procedures). One sample from each 4 foot section of core will be preserved by covering the ends of the plastic sample tube with Teflon tape and plastic end caps. All soil samples will be placed on ice in a cooler in preparation for transport to a State certified analytical laboratory for possible chemical testing.

The soil core will be field screened for volatile hydrocarbons using an Organic Vapor Meter (OVM). Soil samples selected for screening will be placed in a plastic zip-lock bag and allowed to sit in the sun and volatilize for approximately five minutes. The tip of the OVM will then be inserted into the bag and a reading will be recorded in the geologic log of the boring.

A grab groundwater sample will be collected in each Geoprobe boring by lowering a Teflon or stainless steel bailer into the groundwater and hand retrieving the full bailer to the surface. The groundwater from each boring will be transferred to three 40 ml VOAs and one amber liter jar, and placed on ice in the cooler containing the soil samples.

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After the collection of soil and groundwater samples from each boring, the Geoprobe borings will be grouted back to surface grade using a neat cement and 5% bentonite mix. Grouting will be done under the supervision of the ACDHCS.

The soil and groundwater samples selected by the field engineer for chemical testing will be transported under strict chain-of-custody to a State of California certified analytical laboratory. Soil and groundwater samples will be analyzed for TPHG, TPHD, BTEX, and MTBE using EPA Methods 8015 and 8020. One groundwater samples will be analyzed with EPA Method 8260 to confirm the presence and concentration of MTBE. (the highest MTBE spl)

Task 2: Monitor Well Installation

Monitor wells MW-1, MW-2, MW-3, and MW-4 will be constructed at the approximate locations shown on Figure 5. The wells will be installed using a truck-mounted drill rig equipped with 10-inch hollow-stem augers. The monitor wells will be completed to a depth of 20 feet and constructed with 4-inch diameter ASTM schedule 40 PVC casing. Screened well casing will be placed from a depth of 5 feet to 20 feet. Monterey No. 3 silica sand filter pack will be placed between the casing and the annular space of the borehole to approximately one foot above the top of the well screen. One foot of hydrated bentonite pellets will be placed above the filter pack. The well will be completed to the ground surface with a mixture of Portland cement and 5% bentonite. A surface-flush traffic-rated manhole and cover will be placed over the well head.

While drilling, soil samples will be collected by advancing a modified California type sampler containing a three six inch brass liners into the undisturbed soil ahead of the auger bit at five foot intervals. A Bonkowski & Associates field engineer will log each soil sample using ASTM Method D-2488, Description of Soils (Visual-Manual Procedures). The middle six inches of the sample will be field screened for volatile hydrocarbons using an OVM. The lower six inches of each sample will be preserved at each end by covering the ends of the liner with Teflon tape and plastic end caps. All soil samples will be placed on ice in a cooler in preparation for transport to the State certified analytical laboratory for possible chemical testing.

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The newly constructed monitor wells will be developed, approximately 24 hours after sealing, by over pumping and block surging until the discharge water is relatively free of settleable solids and the pH, conductivity and temperature have stabilized to within 10% on three successive readings. All well development equipment coming into contact with the water will be decontaminated by washing in an Alconox solution followed by tap and deionized water rinses.

Top of casing elevations of all newly installed monitoring wells will be determined by a California State-licensed surveyor to the same datum as the existing monitoring wells. Vertical survey measurements will be made to an accuracy of +/- 0.01-foot.

Groundwater samples will be collected from wells MW-1, MW-2, MW-3, and MW-4 for chemical analysis. Prior to sampling, the water level elevation will be determined in each well with a power sounder. The results of these measurements will be used to determine groundwater flow gradients in the vicinity of the site. Water levels will be measured to the nearest 0.01-foot.

Each well will then be purged of a minimum of three casing volumes of water or until dry using either a disposable polyethylene bailer or a 2-inch submersible Grundfos Rediflo II pump. All purging equipment will be properly decontaminated prior to use at each well. The wells will be sampled when either: the water level returns to at least 80 percent of its static level, or the water quality parameters pH, conductivity, and temperature are within 10% of each other on three consecutive readings.

Water samples will be collected from the total depth of the well using dedicated and disposable polyethylene bailers. Water samples will be placed in laboratory prepared containers and placed on ice in a refrigerator cooler to cool the samples to a maximum temperature of 4°C. The groundwater samples will be transported directly to a State certified analytical laboratory under Chain-of-Custody.

The drill cuttings and decontamination water resulting from the well installation will be contained in 55-gallon DOT drums. These materials will be disposed of properly, pending a review of chemical test results.

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All necessary permits, including well installation permits, for the work as detailed in this Plan will be approved by the appropriate regulatory agencies before the commencement of any site activities.

Task 3: Data Analysis

Bonkowski & Associates will evaluate all subsurface data acquired through the site work completed per this Workplan and previous site data collected at the site to assess the extent and magnitude of hydrocarbon contamination and identify contaminant migratory pathways.

The evaluated data will be tabulated and presented in a format which will include:

- A water level map for the sampling area.
- Geologic cross-sections showing the distribution of subsurface materials and contaminants, and the connectivity between the lower and upper water zones.
- Tabulated soil and groundwater chemistry data from all current and previously conducted site activities.
- Isopleth maps showing the distribution of TPHG, TPHD, BTEX, and MTBE constituents for all borings and wells at the site.
- A discussion evaluating the extent of the contamination.

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4.0 REMEDIAL OBJECTIVES

The State and Federal standards applicable to groundwater at the Golden Gate Petroleum Oakland Cardlock site are based on Maximum Contaminant Levels (MCLs) established for hydrocarbon concentration and odor and taste thresholds. The thresholds are:

Aromatic Hydrocarbons		
Benzene	1.0 µg/l	California Primary MCL[1]
Toluene	42 µg/l	Taste and odor threshold (U.S. EPA)[2]
Ethylbenzene	29 µg/l	Taste and odor threshold (U.S. EPA)[2]
Xylenes	17 µg/l	Taste and odor threshold (U.S. EPA)[2]
MTBE	14 µg/l	Proposed public health goal (OEHHA)[3]
Hydrocarbon Mixtures		
Diesel or Kerosene	100 µg/l	Taste and odor threshold (U.S. EPA)[4]
Gasoline	5 µg/l	Taste and odor threshold (SWRCB)[5]

too conservative;
gw's not
being used
for drinking

[1] Primary MCLs are based on health effects data, but contain other information relating to technical and economic feasibility of attainment in a water distribution system.

[2] Federal Register, Vol. 54, No. 97, pp. 22138, 22139.

[3] Office of Environmental Health Hazard Assessment

[4] 1980 Health Advisory. Documents states that the 100 µg/l level should be health protective for 10 days of exposure of less. No lifetime exposure advisory has been developed. However, lifetime health advisories are normally at least ten-fold lower than 10-day advisories. Therefore, a level of 10 µg/l would be a reasonable estimate of lifetime health protective level for diesel or kerosene.

[5] McKee & Wolf, *Water Quality Criteria*, 2nd Ed., State Water Resources Control Board (1963, 1978) p. 230.

No explicit remedial action goal for soil and groundwater has been stated by the local implementing agency or California regulations for the site. The general goal for soil and groundwater remediation is stated by the State Water Resources Control Board (SWRCB) in the State's Non-Degradation Policy. State Water Resources Board Resolution No. 68-18 directs that there be no degradation in the quality of water and requires the attainment of "background" water quality and the remediation of contaminated soils to prevent further contamination. If background levels cannot be attained, the alternative cleanup levels, less stringent than background, shall:

1. be consistent with maximum benefit to the people of the state
2. not unreasonably affect present and anticipated beneficial uses of such water
3. not result in water quality less than that prescribed in the Water Quality Control Plans and policies adopted by the State Regional Water Boards.

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Therefore, the proposed cleanup level is to be consistent with the protection of beneficial uses, the limitations of cleanup techniques, and the achievement of water quality control standards.

5.0 REMEDIAL TECHNOLOGY SCREENING

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A range of remedial action technologies is available to control, remove, treat, or dispose of hydrocarbons in soils and groundwater. However, the site conditions make many of these potential technologies ineffective. This initial screening will determine which of these technologies are immediately applicable to the site. This screening will only identify those technologies that are proven with a history of successful use, and that have been approved by the Cal EPA at other underground storage tank facilities. The screening will eliminate the use of impractical technologies. The most promising technologies will then be combined into three alternatives, which will then be compared to determine which is the most cost-effective corrective action.

Table 1 outlines the general remedial approaches and associated technologies for remediation which may be applicable to soils and groundwater at the site. The results of a screening that considered the advantages and disadvantages of each technology are summarized in Table 2. The evaluation considered the properties of the contaminants, the distribution of contaminants in soils and groundwater, the beneficial uses of groundwater, and the potential impact to other resource users. The results of the remedial technology screening are described below.

5.1 Hydrocarbon Properties

Petroleum fuel hydrocarbons consist of a range of compounds. The principle chemicals of concern from a regulatory and health perspective that are found in petroleum are benzene, toluene, ethylbenzene and total xylenes (BTEX) and methyl tertiary butyl ether (MTBE). These chemicals can comprise up to 50 percent of unleaded gasoline. The physical and chemical properties of BTEX and MTBE compounds are shown in Table 3. Summaries of health, regulatory, and aquatic based standards for these compounds are provided in Appendix B.

BTEX and other hydrocarbons are only slightly soluble in water. The low solubility in water makes substantial recovery of hydrocarbons through groundwater extraction difficult, if not impractical. Hydrocarbons are more volatile than water and can be effectively recovered through the use of soil vapor extraction technology and through air sparging.

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Despite the low solubility of these hydrocarbons in water, the principle mode of hydrocarbon movement is as a dissolved component in groundwater. The movement of groundwater is related to the groundwater gradient, the permeability of the aquifer material, and the combined effects of groundwater pumping and recharge. The migration of hydrocarbons as a dissolved component of groundwater is also inhibited by natural processes including adsorption, dilution, volatilization, and chemical and biological degradation.

MTBE is very soluble in water. The high solubility in water makes substantial recovery of hydrocarbons through groundwater extraction effective compared to BTEX compounds, but treatment is difficult and expensive. MTBE is more volatile than water and can be effectively recovered through the use of soil vapor extraction technology and through air sparging. The principle mode of MTBE movement is as a dissolved component in groundwater. The migration of MTBE as a dissolved component of groundwater is not inhibited by natural processes including adsorption, dilution, and chemical and biological degradation.

5.2 Source Control

In August 1998, one 8,000 gallon and four 12,000 gallon underground storage tanks, product lines, and dispenser islands were removed from the site and approximately 1,300 cubic yards of hydrocarbon impacted soil were removed from the site. This action, and the applicable technologies, are therefore not considered further.

5.3 Low Temperature Thermal Stripping

The costs are comparatively high and the specialized equipment required is not readily available. Emission controls are required to sustain combustion and permits are required for air emissions. This alternative also requires soil excavation. There is no continuous stream of contaminated material at the site and heat recovery would require close monitoring. Finer grained materials typical of the site will not readily release residual phase hydrocarbons to allow volatilization. High moisture content soil, such as that in the capillary fringe at the site, may have high heat capacities and their remediation is not cost-effective using this method. Routine health and safety must include safety rules for operating around high temperature equipment. This technology offers no advantage over excavation and disposal or groundwater extraction, and is not considered further.

5.4 High Temperature Thermal Stripping

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Incineration is favored when there is a relatively small quantity of highly toxic material which can be destroyed by a mobile unit or when there is a continuous stream of waste which can be treated in a permanent installation. It is used in combination with some form of heat recovery. In addition, mobile steam strippers are not readily available and permanent facilities do not exist. Extensive testing is required to evaluate the effectiveness of the incineration process. Therefore, incineration is eliminated from further consideration.

5.5 In-Situ Biodegradation

Hydrocarbon degradation is accomplished with the aid of naturally occurring micro flora or through the enhancement of hydrocarbon degrading activities of naturally occurring micro flora with the addition of oxygen and nutrients, and the adjustment of the environment. This technology has a limited track record, and there are severe difficulties in delivering oxygen, nutrients, and pH-adjusting chemicals evenly to the contaminated media, and controlling species growth and temperature. There is no adequate way to ensure an even distribution of the nutrients to the hydrocarbon impacted strata. Channeling of nutrients in the soil and bedrock may result in non-homogeneous treatment and treatment rates are reported to be slow when hydraulic conductivity is low. It is difficult to control or monitor the process. The by-products of the technology are not completely known and MTBE is not readily biodegraded. This option offers no advantages over soil excavation or groundwater extraction, so it is not considered further.

5.6 Soil Excavation

Soil excavation is currently the most cost-effective cleanup technology for shallow contaminated soils where structures, right-of-ways, property lines, and underground utilities do not limit the extent of excavations. Mechanical equipment is used to excavate impacted soil which is then tested and transported to a permitted soil recycling or disposal facility, or to a treatment facility. Floating hydrocarbons and dissolved phase hydrocarbons are removed from the excavation cavity by pumping, or treated by sprinkler aeration during the course of the removal operations, enhancing the remedial effort.

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Remaining soils are tested to ensure that all hydrocarbons have been removed. The excavation is then backfilled with clean soil. If impacted soil removal is complete, this alternative is very effective. Often, impacted soil remains beneath structures or roadways, limiting the complete effectiveness of this technology. Soil excavation was used as an IRM during the tank removal and replacement activities. Because of its proven reliability and effectiveness, and the shallow depth to hydrocarbon contaminated soil and groundwater, this technology is appropriate for further consideration for the site.

5.7 On-site Land Farming

In selected situations, land farming of gasoline and diesel contaminated soil and groundwater has been a viable alternative at major manufacturing facilities, but its use at local facilities is still considered experimental. Land farming utilizes natural processes, such as volatilization, biodegradation, or adsorption to decontaminate soil and groundwater. The applicability of land treatment is also site-specific. Its use depends on the volume of soil and groundwater to be treated and the availability of a treatment site within the immediate area. Leachate-control liners and groundwater monitoring around the land treatment area are required to ensure that cross-contamination does not occur. In addition, characterization of the microorganisms in the soils is necessary to evaluate the potential for biodegradation. Land farming may also require groundwater and air quality permits and monitoring. At this location, there is insufficient space to treat contaminated soil and there is substantial automobile at and near the site. If the soil is excavated, it will be more cost-effective to remove it to a landfill than to use land farming techniques. Therefore, land farming is not considered further.

5.8 Vapor Extraction

Vapor extraction is used to volatilize the hydrocarbons in the unsaturated zone and capillary fringe of the soil and draws the vapors into an aboveground treatment system. A number of additional extraction wells, supply laterals, and a system compound would need to be constructed. It is anticipated that the system would need to be operational for an extended period of time, which reduces cost-effectiveness of this option.

5.9 Steam Stripping

Steam stripping is useful for wastes containing high concentrations of highly volatile compounds. This method uses heat from steam to raise water temperature and increase mass transfer and partitioning of volatile compounds into the vapor phase. Steam stripping is limited to applications where volatile compounds have low solubilities and are highly concentrated. Compounds miscible with water are not removed with this treatment. This method is usually cost-effective only where a source of steam exists (such as a steam generating plant at a refinery). If the soil is excavated, it will be more cost-effective to remove it to a landfill than to bring in equipment to steam the soil. Its use at the site is excluded from further consideration.

5.10 Fixation

Fixation involves the use of cementitious material to encapsulate or physically bind the chemicals within a solid matrix. A fixative agent would have to be resistant to long-term weathering by groundwater and capable of solidifying a dissolved pollutant. The fixative agents must be bench-scale tested to evaluate their potential to further pollute the groundwater or form toxic by-products. Since fixation will lower hydraulic conductivity near the injection wells, a large number of closely-spaced injection wells are required. Hydrocarbons are not removed when fixation is implemented. There is a possibility that the chemical reactions may be reversed with time, allowing hydrocarbons to migrate with groundwater flow. This technology is not considered further.

5.11 Soil Washing

This technology is relatively immature, difficult to manage, and may require excavation. If the soil is excavated, it will be more cost-effective to remove it to a landfill than to bring in equipment to wash the soil, replacing the soil, and disrupting the operation of the facility during this process. Therefore, soil washing is eliminated from consideration.

5.12 Groundwater Contamination Control with On-site Treatment

Groundwater extraction, or pump and treat, has proven effective in controlling the migration of dissolved hydrocarbons but has limited effectiveness as a hydrocarbon recovery technique. A long-term permit for a treated groundwater discharge has been obtained from the East Bay Municipal Utilities District (EBMUD). Spray aeration and oxidation, with activated carbon scrubbing, is likely to be accepted as a treatment technology for the permit.

This technology has been shown to be effective in certain situations to control and prevent the off-site migration of dissolved phased hydrocarbons. Because dissolved phase hydrocarbons are present in groundwater at the site and off-site migration of hydrocarbons may have occurred, this technology will be considered further.

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5.13 Dual Groundwater and Vapor Extraction with On-site Treatment

Plume control is established by the installation of a series of hydraulic controls. Controls may consist of a series of extraction wells or collector trenches. Hydrocarbons in groundwater and soil vapor are extracted from the soil and volatilized. The extracted VOCs can be vented, adsorbed on carbon, incinerated or catalytically oxidized. Monitoring downgradient of the system is required to assess effectiveness.

This alternative prevents off-site migration of contaminants. Dissolved-phase hydrocarbons can be recovered and the concentrations of residual hydrocarbons in the unsaturated zone can be reduced. It is a proven technology for substantial remediation of subsurface hydrocarbons at a leaking underground storage tank site where complete removal of contaminants is not required. Extracted groundwater and vapors require treatment. Treatment can be accomplished using an air stripping column, carbon filters, thermal oxidation, and/or catalytic oxidizer. This technology will recover lighter end aromatic hydrocarbons. It will not recover heavier hydrocarbons or hydrocarbons mineralized into the soil structure (e.g. benzene). This technology will be considered further.

5.14 Separate Phase Hydrocarbon Recovery

Passive or active hydrocarbon recovery is extremely effective in preventing further degradation of groundwater and soils, and in eliminating potential vapor plume migration, fire and explosion risks. SPH recovery is performed with extraction wells and trenches and is often done in conjunction with groundwater extraction. Since SPH is not present at the site, this option is not considered further.

5.15 Air Sparging

This method involves the injection of air into the contaminated groundwater zones. The air injection volatilizes dissolved phase aromatic hydrocarbons and enhances in-situ biodegradation. Effectiveness is limited to those portions of the aquifer in which the air

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stream comes in contact. Since air streams are known to travel through the least resistant flow pathways, uniform treatment is not possible. Some portions of the aquifer may not be treated as a result of the channelized air flow. It is also difficult to monitor the effectiveness of the treatment. Air sparging, when conducted in concert with soil vapor and groundwater extraction can be effective in reducing the concentrations of residual hydrocarbons in the groundwater and vadose zone soils. Therefore, this technology will be further considered.

5.16 Institutional Controls

Deed restrictions could be placed on the property prohibiting subsurface utility work without preparation of a health and safety plan. Institutional controls are not deemed necessary because the sites previous operation as a gasoline station provides adequate warning that the presence of hydrocarbons in soils can be anticipated.

5.17 Groundwater Monitoring

Dissolved hydrocarbon plumes generally reach a limit where the rate of migration is equal to the rate of attenuation by biological processes and dilution. Monitoring groundwater quality and flow direction ensures that the dissolved hydrocarbon plume in the groundwater remains within these limits. Monitoring is often performed in conjunction with other remediation technologies to verify cleanup effectiveness, especially when cleanup activities leave residual hydrocarbons in groundwater or soil. This technology is considered further.

5.18 Non-Applicable Remedial Technologies

Based on the preliminary comparison of remedial technologies summarized above, source control, thermal stripping, in-situ biodegradation, on-site land farming, in-situ steam stripping, in-situ soil fixation, soil washing, separate phase hydrocarbon recovery, and institutional controls are inappropriate for application at the site.

6.0 REMEDIAL ALTERNATIVES

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The criteria for selecting an alternative to remediate hydrocarbon contamination at the site includes the time required to achieve required cleanup levels, the applicability and dependability of the selected technology, the likelihood of regulatory approval of the proposed solution, and the cost of the alternative compared to the relative risks to human health and the environment. Each proposed remedial action alternative described herein is a combination of the process options which passed the initial feasibility screening of the previous section. The remedial technologies applicable to mitigate the soil and groundwater contamination at the site are:

1. Excavation
2. Air Sparging
3. Dual Vapor and Groundwater Extraction
4. Groundwater Extraction
5. Groundwater Monitoring

Each alternative includes measures to satisfy the soil and groundwater remediation goals of preventing impacts to the beneficial uses of groundwater by others. Although each of the remedial technologies could potentially meet remediation goals, they differ in their cost-effectiveness, their degree of short- and long-term protection of human health and the environment, and are limited to either soil or groundwater remediation. In combination, these technologies form remedial alternatives which address both soil and groundwater contamination, and more effectively meet the remediation goals stated in Section 4.0.

The conceptual design of the combined technologies is provided below, along with a comparative analysis to determine which remedial alternative has the highest benefit-to-cost ratio while still fully satisfying remediation goals. The remainder of this section describes these conceptual designs using combinations of the three remedial technologies which have been determined to be appropriate to the site.

6.1 Remedial Action Alternative No. 1 - Soil Excavation and Groundwater Monitoring

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Remedial action alternative no. 1 includes soil removal, groundwater removal from the excavation, treatment and discharge, and resurfacing with an asphalt cover. The cover system would be graded to resemble the existing surface water drainage patterns. Soil contaminated with petroleum fuel hydrocarbons would be removed from the areas that were not excavated during the IRM activities in the approximate areas shown in Figure 6. The soil would be removed using an excavator, backhoe, and front loader, and direct loaded for transport to be stockpiled at an appropriate landfill for sampling, hazard classification, and disposal. The depth of the excavation would be approximately 15 feet, and limited between the previously excavated area and the property lines on Kennedy Avenue. It is assumed that approximately 5 feet of clean material will be removed from the surface of the excavation. The excavation would be limited by soils void of petroleum fuel hydrocarbons, BTEX and MTBE. For the purposes of this feasibility analysis, it is estimated that approximately 3,200 cubic yards of soil would be removed.

Shallow groundwater would be pumped from the excavation while digging, and placed in baker tanks for testing. For the purposes of this analysis, it is estimated that approximately 40,000 gallons of water would be removed from the excavation, which would be de-watered using a vacuum truck. The sidewalls of the excavation may be shored to provide for a safe vertical inclination. Soil samples would be collected from the sidewalls of the excavation at a frequency of one sample every 20 linear feet, and tested for TPHG, TPHD, BTEX, and MTBE by EPA modified methods 8015 and 8020. The excavation would then be backfilled with clean imported fill placed above a filter fabric to protect the granular backfill from silt infiltration.

Alternative no. 1 would result in high hydrocarbon mass removal from the accessible unsaturated zone. This alternative provides controls to ensure the extraction of hydrocarbons from the smear zone and those already present within groundwater bearing units.

This alternative would also include groundwater monitoring and reporting. Monitor wells would be installed and used to evaluate the effectiveness of the removal action over a two year period. No actions would be taken to recover hydrocarbons remaining in soils or groundwater, and these would be allowed to attenuate. Groundwater elevations would be measured and groundwater samples collected quarterly to determine the direction of groundwater flow and to identify changes in contaminant distribution. Results of monitoring would be reported to the ACDHCS on a quarterly basis. The cost to perform this work is estimated to be $380,500, including two years of groundwater monitoring and reporting. The costs are outlined in Table 4.

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6.2 Remedial Action Alternative No. 2 - Air Sparging and Vapor and Groundwater Extraction and Monitoring

Remedial action alternative no. 2 includes the groundwater extraction from the collector trench, air sparging from sparge points which will be installed around the former tank cavity, and dual vapor extraction from the newly placed vapor extraction wells, EW-1, EW-2, EW-3 and EW-4, installed at fifty foot spacing around the former underground tank, and groundwater monitoring. Air sparging involves the injection of air into the contaminated groundwater zones. The air injection volatilizes dissolved phase aromatic hydrocarbons and enhances in-situ biodegradation. Soil vapor extraction would be performed on shallow soils on-site through the vapor extraction wells. Soil vapor extraction is the most effective method for removing hydrocarbon mass from the subsurface, provided that sufficient air flow is maintained through the contaminated soil areas. The method provides the added benefit of maintaining oxygen levels to promote the in situ bio-degradation of contaminants. The actual number and spacing of the sparge points and vapor extraction wells would be determined by a evaluation of data from 30 day production test of EW-3. An initial review of the subsurface conditions, suggests that two to four vapor extraction wells would be required.

Discharges from both the SVE and groundwater air stripping systems would be treated by Spray aeration and oxidation and activated carbon scrubbing prior to release to the atmosphere. The extracted groundwater would be discharged to the sanitary sewer. The system would operate until groundwater monitor wells are void of petroleum fuel hydrocarbons for eight (8) consecutive quarters of monitoring.

This option will eliminate the source area hydrocarbons, and mitigate the potential downgradient migration of contaminants left in place after the initial excavation. The asphalt cover will further impede the infiltration of groundwater through residual hydrocarbons remaining in the soils. After the dual vapor and groundwater extraction system is turned off, natural attenuation and bio-restoration will degrade any existing residual phase hydrocarbons. Through additional groundwater monitoring, the effectiveness of the natural attenuation and bio-restoration will be determined. Any additional contamination of the shallow will trigger the operation of the extraction system.

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The cost of this option, including assumptions regarding the length of time of groundwater extraction system operation, is estimated to be $251,000. The costs are outlined in Table 5. Groundwater monitoring would be implemented in the planned extraction wells for a two year period to evaluate the remedial treatment system effectiveness and used to determine when to turn off the system and allow passive bioremediation to become the primary remediation technology. Groundwater monitoring will continue until four (4) consecutive quarters show no rebound of hydrocarbons and confirms the effectiveness of the remedial alternative.

6.3 Remedial Action Alternative No. 3

Remedial action alternative 3 would include groundwater extraction from the collector trench, placed in the former underground storage tank cavity (Figure 7). The advantage to this alternative is that it addresses hydrocarbons down gradient of the underground tank. Groundwater would be treated by spray aeration, oxidation and carbon scrubbing, and discharged to the sanitary sewer.

A radius of influence study, monitoring and adjustment of the system will be necessary to confirm the containment of the plume. Additional wells may be required to provide adequate hydraulic control. For the purposes of this estimate, pumping is assumed to be from the collector trench.

The remedial objective is to reduce hydrocarbon concentrations to below State MCLs. This option can eliminate potential downgradient migration of contaminants. However, due to the nature and quantity of the gasoline released, this alternative has an indefinite time line and several thousand volumes of groundwater will have to be extracted. Pumping may be required for a lengthy time period before all the hydrocarbons are treated or removed. Pump and treat systems can operate for several years, with only minimal improvements to groundwater quality.

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This alternative would also include groundwater monitoring and reporting. Monitor wells would be installed and used to evaluate the effectiveness of the remedial alternative over a two year period. Groundwater elevations would be measured and groundwater samples collected quarterly to the remediation effectiveness. Results of monitoring would be reported to the ACDHCS on a quarterly basis.

The costs of groundwater extraction and treatment are estimated to be approximately $140,600. The costs for two (2) years of treatment are outlined in Table 6.

6.4 Cost-effectiveness Comparison

The cost of the combined remedial alternatives are summarized below. The cost assumptions are presented in Tables 4 thru 6. As shown, the costs range from $140,600 for groundwater extraction and monitoring; to $251,000 for the cost of air sparging, dual soil vapor and groundwater extraction, and monitoring; to $380,500 for soil excavation, groundwater extraction and groundwater monitoring.

	Remedial Alternatives	Estimated Cost
1.	Soil Excavation and Groundwater Monitoring	$380,500
2.	Air Sparging, Soil Vapor and Groundwater Extraction, and Groundwater Monitoring	$251,000
3.	Groundwater Extraction and Monitoring	$140,600

7.0 RECOMMENDED CORRECTIVE ACTION

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Under the limitations of the cost estimates provided, groundwater extraction and groundwater monitoring (Alternative 3) is the recommended and most cost-effective alternative. This alternative is immediately applicable and is a reliable and proven means of eliminating the threat of dissolved phase hydrocarbons to downgradient receptors. A conceptual description of the proposed remedial treatment alternative is presented below.

7.1 Groundwater Monitoring

Additional monitor wells may be required when the results of the site investigation (Task 1) are available to evaluate the vertical and lateral extent of the dissolved hydrocarbons downgradient of the site. The wells would be completed to a depth of approximately 20 feet. The wells would be monitored to determine the impact of groundwater extraction on the dissolved hydrocarbon plume which may be migrating off-site. Possible well location are shown on Figure 7. A well construction schematic for this is shown in Figure 8.

Groundwater monitoring would be performed in the extraction and monitor wells to ensure that the dissolved hydrocarbon plume is stable. These wells would be used together to form the established plume boundary and to trigger additional extraction in the event of contaminant rebound after the system operation is terminated.

Periodic monitoring of groundwater would be performed and the results reported quarterly to ACDHCS. The monitoring would include the measurement of depth to groundwater in all site wells on a quarterly basis. Groundwater samples would also be collected from all wells for analysis for TPHG, TPHD, BTEX, and MTBE.

7.2 Groundwater Extraction

Shallow groundwater within the identified plume area occurs in fine grained sediments with low to moderate permeability. The most successful system for hydraulically controlling and extracting source area contaminated shallow groundwater is anticipated to be the collector trench installed in the coarser backfill of the former underground storage tank excavation.

7.3 Groundwater Treatment and Disposal

Groundwater pump and treat alternatives provide hydraulic control and limited hydrocarbon recovery. This technology proposed at the Oakland Cardlock to provide hydraulic control of hydrocarbon impacted groundwater. Requirements for groundwater treatment are dictated by the discharge requirements that are specified in the EBMUD discharge permit.

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An air stripper and oxidation or thermal destruction of VOCs will be used to treat groundwater extracted at the site. Extracted vapors are treated and discharged under a permit from the local air district. Treatment systems are generally selected to enable economic operation. Activated carbon may be used as a final scrub of the vapor. When breakthrough monitoring determines that the carbon has reached its capacity for hydrocarbons it is sent to an outside service for regeneration and reuse. Operating costs of activated carbon decrease with decreasing hydrocarbon vapor concentration.

7.4 Permits

In addition to approval from the ACDHCS to implement this plan, permits and notifications are required from the following public agencies:

1. Bay Area Air Quality Management District Permit to Construct
2. City of Oakland Building Permit
3. Alameda County Well Installation Permit

Each of the required permits is relatively routine and regulatory approval is not anticipated to delay the implementation of this plan.

8.0 SCHEDULE

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The preferred remedial action alternative for the Golden Gate Petroleum Oakland Cardlock is Alternative No. 3. This report is being submitted to the ACDHCS for their review and concurrence with the preferred remedial action. Once formal approval of the remedial action is received from ACDHCS, Bonkowski & Associates will prepare a final remedial design document for bidding the work. This document would contain the following elements: Final schedule for remediation activities, site plan with points of compliance, design standards and technical specifications, excavation limits, collector trench piping, backfill, flow diagram, effluent treatment and disposal plans, and contingency plans. Once bids have been obtained, a bid package will be sent to the Underground Storage Tank Cleanup Fund for pre-approval and work will begin after the costs have been pre-approved.

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9.0 REFERENCES

Bonkowski & Associates, Inc., "Tank Cavity Closure Report, Golden Gate Petroleum: Oakland Cardlock," 16 September 1998.

Bonkowski & Associates, Inc., "Interim Remedial Measures Workplan, Oakland Cardlock," 14 August 1998

Bonkowski & Associates, Inc., "Supplemental IRM Workplan, Oakland Cardlock," 18 August 1998

Table 1. General Remedial Approaches and Associated Technologies for Remediation at Golden Gate Petroleum Cardlock, Oakland, California.

General Remedial Approach	Associated Technology
Soils Remediation	
Source Control	Identify and repair leaks; or remove leaking tank and impacted soil around the tank.
Excavation/on-site treatment of soils	Excavate all or part of residual phase hydrocarbons in soil; treat by on-site incineration, on-site landfill, or land treatment. Space limitations at the site limit remove this approach from further consideration.
Excavation /off-site treatment or disposal	Excavate all or part of residual phase hydrocarbons in soil; dispose of in commercial incinerator or commercial landfill.
In-situ treatment	Biodegradation, vapor extraction, in-situ steam/air stripping, soil washing, chemical neutralization.
Physical Containment	Slurry wall, fixation. Shallow groundwater at the site limits the effectiveness of this option. Not considered further
Institutional Controls	Property and deed restriction, groundwater monitoring, risk assessment, and well use survey.
Groundwater Remediation	
Contaminated groundwater control and on-site treatment.	Install hydraulic barriers (may be utilized with physical control options); recover and treat contaminated groundwater; implement long-term groundwater monitoring.
Contaminated groundwater and soil gas extraction and on-site treatment	Pump groundwater and vapor from one or more recovery wells to a collection point; treat biologically, by air stripping, by catalytic oxidizer, by carbon adsorption, by separation, by coalescing, by ultraviolet, or other suitable methods.
Floating Hydrocarbon Recovery	Recover floating product from control points including wells and trenches.
Monitoring Only	Groundwater monitoring. No action.

Table 2. COMPARISON OF REMEDIAL TECHNOLOGIES

Technology	Description	Advantages	Disadvantages
Source Control	Identify and repair leaks; monitor or remove underground storage tanks. This action is required if the tanks or lines are found to leak.	Will minimize the possibility of future hydrocarbon spills; immediate application.	Source control leak and spill prevention measures were undertaken in August 1998 when the underground storage tanks, product lines, and dispenser islands were removed and the tank cavity and dispenser island area were overexcavated. This is not a viable option.
Low Temperature Thermal Stripping	Low Temperature Thermal Stripping (LTTS) of hydrocarbons in soil. Contaminated soil is fed into a rotating kiln where high temperature gases cause hydrocarbon contaminants to volatilize. Vapors are burned or collected. Typically the stripper is rotated to provide good contact between soil particles and hot gases. Vapors are passed through a catalytic converter or a carbon filter. Exhaust gases are passed through a wet scrubber or baghouse to remove fine particulates, then vented.	The advantage of this method is that it provides relatively simple means of cleaning contaminated soil. The treatment time is short, and treated soils can be used as backfill. Destruction and removal efficiencies in excess of 99.99% are commonly achieved. Attractive in cases where a relatively small quantity of highly toxic material has to be destroyed or where there is a continuous stream and heat recovery is possible; and where equipment is readily available.	The disadvantages are that the costs are comparatively high and specialized equipment that is not readily available is required. This alternative requires soil excavation; permits required for air emissions; emission controls required to sustain combustion. There is no continuous stream of contaminated material and heat recovery would require close monitoring. Soils which are heavily contaminated with hydrocarbons cannot be used in LTTS systems due to the risk of fire of explosion. Hydrocarbon adsorbed to the finer grained materials typical of the site, will not volatilize readily. High moisture content soil may have high heat capacities and are not cost-effective. Routine health & safety must include safety rules for operating around high temperature equipment. This technology offers no advantage over excavation and disposal, and is not considered further.

Table 3. COMPARISON OF REMEDIAL TECHNOLOGIES (continued)

Technology	Description	Advantages	Disadvantages
High Temperature Thermal Treatment	Incineration of contaminated soil. Using the rotary kiln method, soils are fed into a closed chamber and incinerated with the exhaust from a propane flame. Typical combustion temperatures are in the 750 to 1100°C range. Fluidized bed incinerators are also used, and incorporate a bed of sand for agitation and heat transfer. Typical combustion temperatures range from 750 to 870°C.	The advantage of this method is that is provides a relatively simple means of cleaning heavily contaminated soil. All hydrocarbons are incinerated during the treatment. Other organic compounds are oxidized. This technology is most suitable for soils that are difficult to treat.	This technology is classified as developmental, particularly with respect to petroleum contaminated soil. Ash produced from the process may be toxic and needs to be captured. Local air monitoring regulations require extensive effluent gas monitoring. High moisture content soil may have high heat capacities and are not cost-effective. There is shallow groundwater at the site. The soil will have a high moisture content. Since this method is developmental in nature, it is no longer considered.
In-situ Naturally Occurring Bio-degradation	Hydrocarbon degradation by natural occurring micro flora.	Has demonstrated track record of effectiveness for lighter end hydrocarbons with large areal distributions, and for diesel fuel and jet fuel sites (e.g. refineries, airports, railroad fueling facilities). No disruption of services at the site. This technology is particularly useful for deep zone contaminants below excavation limits.	Limited success in areas of low porosity soils, high contaminant concentrations, and MTBE in soil and groundwater. The complete degradation rate is slow and MTBE is has not been shown to biodegrade. Ground-water will continue to be impacted during process. High concentrations of MTBE at the site make this an unworkable alternative. Therefore it is not considered further.
In-situ Enhanced Bio-degradation	Enhancement of hydrocarbon degrading activities of naturally occurring micro flora through the addition of oxygen and nutrients, and adjustment of the environment.	Technology with a limited track record. Minimizes disruption of services at the site. May be the only technology available to deal with special cases where the contamination is below the excavation limits, very large sites with extensive petroleum contamination, and diesel or jet fuel contamination.	Difficulties in delivering and ensuring even distribution of oxygen, nutrients and pH-adjusting chemicals; and species control and temperature control. Channeling may result in non homogeneity of treatment. Treatment rate will be slow when hydraulic conductivity is low and fracture controlled. It is difficult to control or monitor the process. The by-products of the technology are not completely known. High concentrations of MTBE at the site make this an unworkable alternative. Therefore it is not considered further.

Table 3. COMPARISON OF REMEDIAL TECHNOLOGIES (continued)

Technology	Description	Advantages	Disadvantages
Excavation and Off-Site Commercial Landfill	Excavation of hydrocarbon containing soil. Transport to and disposal at a commercial landfill.	Removes source materials from the site. Reduces chances of continuing groundwater contamination. Suitable for a small site with a confined plume. This is a proven technology.	Requires soil excavation. Health and safety considerations involving a large excavation and heavily contaminated soil. This is a viable alternative for the site.
Land Treatment	Tilling of hydrocarbon-containing soil to volatilize VOCs and the addition of nutrients to stimulate biological degradation.	Allows in-situ treatment of contaminated soil.	Hydrocarbon containing soils at depth below the immediate ground surface must be excavated and treated. The treatment is applied unevenly within the soils; and a substantial percentage of nutrient induced activity is ineffective. There remains a potential for leaching, and substantial leachate control and monitoring is required. The addition of biological nutrients to hydrocarbon bearing materials over a short term has a limited track record for a small site. Since a large percentage of volatilization of hydrocarbons occurs by turning, this practice has no advantage over soils excavation and dry aeration or disposal.

Table 3. COMPARISON OF REMEDIAL TECHNOLOGIES (continued)

Technology	Description	Advantages	Disadvantages
Vapor Extraction (VES)	Removal of volatile organic compounds (VOCs) by application of a vacuum to a system of extraction wells. Hydrocarbons are entrained in a flow of extracted air and removed from the pore spaces of the contaminated soil. Extracted VOCs can be vented, adsorbed on carbon, incinerated, or catalytically oxidized.	Proven technology for remediation of volatile hydrocarbons. Treatment rate can be fast for volatile components in porous soils. Treatment may enhance in-situ biodegradation of organic contaminated soils.	Non homogeneity of subsurface may lead to channeling and uneven treatment. In heavy clays the treatment may be useless. More detailed knowledge of subsurface is needed, such as soil moisture content, kinematic viscosity, porosity of the soil, and soil temperature. This method may be completely ineffective if the contaminants are mainly in the groundwater; under shallow groundwater conditions, or under large seasonal fluctuations in water level. Vapors need to be scrubbed before being vented to the air. Does not completely remove heavier end hydrocarbons with low volatility, and commonly leaves adsorbed concentrations of 100 to 1000 ppm TPH. The presence of a high groundwater level make this an unsuitable alternative. Therefore, this is not considered further.
In-situ Steam/Air Stripping	Use of hot air and steam delivered through drilling assembly. Vaporized organics are condensed and recovered. Hot air is compressed and recycled.	Thorough mixing and homogenization of soil. Results in good treatment in coarse-grained soils. Closed-loop operation. On-line monitoring of treatment rate is possible.	Has only limited field experience. Cannot use high pressure. Channeling of hot air and steam difficult to monitor. No long term track record at small sites with limited contamination. This option offers no advantages over excavation and removal. Therefore, this is not considered further.

Table 3. COMPARISON OF REMEDIAL TECHNOLOGIES (continued)

Technology	Description	Advantages	Disadvantages
Fixation	Immobilization of contaminants by use of appropriate chemicals (e.g. fly ash). Contaminants are rendered insoluble to prevent leaching.	Soil can be fixed in place without need for excavation.	Typically used to immobilize chemically contaminated soil rather than petroleum contaminated soil. Technology is relatively immature. Danger of injecting a potential groundwater pollutant. Possibility of the formation of toxic by-products. Need for numerous closely spaced wells since fixation process will lower hydraulic conductivities. High groundwater levels make containment difficult and the possibility of leaching increases. Experience has been largely limited to fixation of metals and highly toxic organics. Application to soil containing hydrocarbons is questionable. Future land use options may be limited. High groundwater levels at the site makes this an unsuitable option. This option is not considered further.
Soil Washing	Flushing of contamination from soil using appropriate solutions (e.g., surfactants or fresh water). With each pass of solution, hydrocarbons will dissolve and move with the solution. The effluent emulsions require capture and treatment.	Allows cleaning of the soil in-situ. Solutions can be introduced through trenches, injection wells, surface spraying, or infiltration galleries. Cost-effectiveness can be improved with the addition of biodegradable surfactants.	Addition of flushing solution requires careful management. Additional knowledge of subsurface is needed. Inefficient for petroleum hydrocarbons, unless biodegradable surfactants are used; and this requires strict effluent control. Large volumes of effluent require on-site treatment and disposal. Injection wells which could be used to add the solutions are strictly permitted or banned in the U.S. There is a large possibility that a significant amount of hydrocarbons will be left after treatment because of flow channeling. Possibility of intro-ducing a potential pollutant into groundwater. Field experience is limited. Surfactant must be treated at high levels of hydrocarbon contamination. This does not impact dissolved phase contaminants. This option offers no advantages over excavation and aeration, and is not considered further.

Table 3. COMPARISON OF REMEDIAL TECHNOLOGIES (continued)

Technology	Description	Advantages	Disadvantages
Dual Groundwater and Vapor Extraction/On-Site Treatment	Plume control by installation of a series of hydraulic controls. Controls may consist of a series of extraction wells, or cut-off trenches. Monitoring downgradient of the system is required to assess effectiveness. This alternative can be combined with the recovery and recycling of free product.	Prevents off-site migration of contaminants. Both dissolved- and free-phase hydrocarbons can be recovered, concentrations of residual hydrocarbons in the unsaturated zone can be reduced. Proven technology for substantial remediation of hydrocarbons in subsurface at leaking underground storage tank site where complete removal of contaminants is not required.	Requires treatment of extracted groundwater and vapors. Treatment can be accomplished using an air stripping column, carbon filters, thermal oxidation, and/or catalytic oxidizer. The technology will recover lighter end-aromatic hydrocarbons. Will not recover heavier hydrocarbons or hydrocarbons mineralized into the soil structure (e.g. benzene). Requires long-term operation. High groundwater level limits the efficacy of this option, but groundwater extraction can be used to lower the water level and expose the effected soils to the vapor flow. Therefore, this is considered further.
Groundwater Contamination Control/ On-Site Treatment	Plume control by installation of a series of hydraulic barriers (i.e. slurry walls, etc.) to retard contaminant migration.	Prevents off-site migration of contaminants. Separates contaminated and non-contaminated groundwater. Isolated groundwater quality can be improved by naturally occurring bioremediation.	Requires extensive knowledge of the extent of contamination and flow conditions. Physical barriers are very expensive, and subject to weathering. Long-term maintenance and inspection costs expected. Difficult to monitor the effectiveness of naturally occurring remediation processes. This technology will not recover residual hydrocarbons in the unsaturated zone, nor will it remove residual hydrocarbons in the capillary fringe. The technology requires long-term pumping and site management, and prohibits the implementation of the residential development. This technology is a viable alternative for the site.
Floating Hydrocarbon Recovery	Floating product recovery is performed with extraction wells and trenches and is often done in conjunction with groundwater extraction. A system would operate either passively by skimmers, or actively by depressing the water table and skimming.	Passive or active hydrocarbon recovery is extremely effective in preventing further degradation of groundwater and soils, and in eliminating potential fire, vapor plume migration, and explosion risks.	Indefinite time line for passive of active recovery. Groundwater will continue to be impacted by dissolved phase hydrocarbons. Since floating product is not present at the site, this will not be considered further.

Table 3. COMPARISON OF REMEDIAL TECHNOLOGIES (continued)

Technology	Description	Advantages	Disadvantages
Air Sparging	Injection of air into contaminated groundwater zones. The air injection volatilizes dissolved phase aromatic hydrocarbons and enhances in-situ biodegradation.	In-situ treatment of readily available hydrocarbons subjected to the air stream.	Effectiveness is limited to those portions of the aquifer in which the air stream comes in contact. Since air streams are known to travel through the least resistant flow pathways, uniform treatment is not possible. Some portions of the aquifer will not be treated as a result of the channelized air. Difficult to monitor the effectiveness of the treatment. Not a long track record of use, but shown to have some limited effectiveness. Air sparging used in conjunction with vapor and groundwater extraction has been shown to in crease the efficacy of the extraction remediation. This alternative is considered further.
Institutional Controls	Continuous quarterly monitoring and possible deed restrictions. Risk Assessment to evaluate impacts on groundwater and the community. Well use survey to ensure that impacts are limited to the site.	Dangers of excavation at this site eliminated. Continued naturally occurring bio-degradation and natural attenuation.	Indefinite time-line for naturally occurring biodegradation and natural attenuation. Institutional controls are not deemed necessary because the site's current operation as a gasoline station provides adequate warning that the presence of hydrocarbons in the soil is anticipated. Therefore, this alternative is not considered further.
Groundwater Monitoring	Groundwater monitoring is an effective remedial approach for low concentrations of dissolved hydrocarbons in groundwater. Monitoring of groundwater quality and flow direction ensures that the dissolved hydrocarbon plume in groundwater remains within these limits. Monitoring is often performed in conjunction with other remediation technologies to verify cleanup effectiveness especially when a cleanup leaves residual hydrocarbons in groundwater or soil.	Dissolved phase hydrocarbon plumes generally reach a limit where the rate of migration is equal to the rate of dilution and attenuation by biological processes. Most cost effective method for dealing with residual subsurface gasoline that has a low impact on air, off-site water and soil.	Indefinite time line for natural attenuation and in-situ bio-remediation. This alternative realistically views excavation of soils at the site as a risk to the health and safety of the area. Property transfer may be more difficult with known residual subsurface contamination on-site. Since current contamination does not pose an imminent threat to other potential ground water users, and monitoring results do not indicate that the dissolved hydrocarbon plume is migrating outside of the established plume limits, monitoring is a viable technology for this site.

Table 3. Physiochemical Properties of Volatile Aromatic Hydrocarbons

	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
Formula	C_6H_6	C_7H_8	C_8H_{10}	C_8H_{10}	$CH_3OC_4H_9$
CAS#	71-43-2	108-88-3	100-41-4	o: 95-47-6 m: 108-38-3 p: 106-42-3	1634-04-4
Molecular Weight	78.12	92.13	106.16	106.17	88.15
Density (gm/ml)	0.88 (20°C)	0.87 (20°C)	0.87	o: 0.88 m: 0.86 p: 0.86	0.73
Vapor Pressure (torr)	76-80 (20°C) 100 (26°C)	10-20 (20°C) 20 (25°C)	7 (20°C) 7.1 (26°C)	5-7** (20°C)	245 (25°C)
Water Solubility (mg/L)	1,750 (10°C) 1,780-1,800 (25°C)	515 (20°C) FW-535 (25°C) SW-379 (25°C)	152 (20°C) FW-161 (25°C) SW-111 (25°C)	o: 170 m: 146 (25°C) p: 156	43,000
$\text{Log}(K_{ow})$***	1.95-2.13	2.21-2.69	3.15	2.77-3.20**	1.1
Organic Carbon Partition Coefficient (K_{oc})	65-83 (25°C)	300-339 (25°C)	1,100	794	10
Henry's Law Constant (dimensionless)	0.22	0.24	0.34	0.27	0.018

Table amended from: de Vlaming, V.L., "Monocyclic Aromatic Hydrocarbons: A Water Quality Assessment, Water Quality Report No. 88-13," California State Water Resources Control Board, December 1988.

Abbreviations:
CAS# - Chemical Abstracts Service Registry Number;
FW - Freshwater; SW - Seawater;
o - ortho; m - meta; and p - para (isomers of xylene).

** Range of all three isomers

*** Log of octanol-water partition coefficient.

Table 4. Cost Estimate to Implement Remedial Action Alternative No. 1

Task	Estimated Cost
Soil Excavationl 4,800 yds^3 soil	$65,000
Transport and Disposal 3,200 yds^3 soil	$140,000
Backfill 4,800 yds^3 soil	$125,000
Pump and Dispose of Groundwater	$25,000
Laboratory Analysis	$9,500
Quarterly Groundwater Monitoring @ 8K x 2 yrs	$16,000
	$380,500

Table 5. Cost Estimate to Implement Remedial Action Alternative No. 2

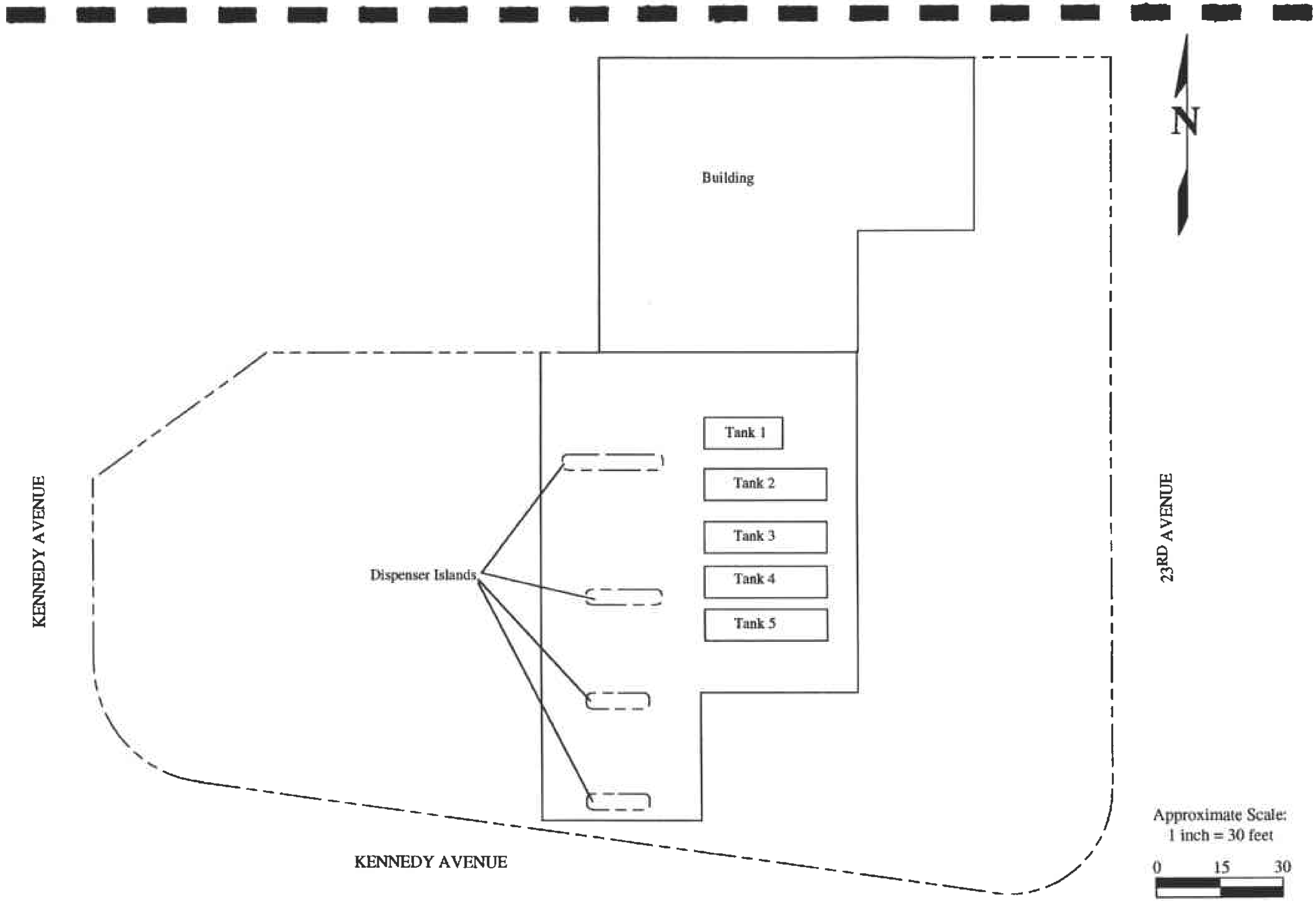
Task	Estimated Cost
Purchase and Install RSI SAVE II Dual Soil Vapor and Groundwater Extraction and Air Sparging System	$100,000
Install Extraction Wells, Sparge Points and Lateral Conduits	$35,000
2 yrs O&M on Extraction System @ 48K x yr	$96,000
Quarterly Groundwater Monitoring @ 8K x 2 yrs	$16,000
Reporting @ 2K x 2 yrs	$4,000
	$251,000

Table 6. Cost Estimate to Implement Remedial Action Alternative No. 3

Task	Estimated Cost
Construct and Install Groundwater Extraction and Treatment System	$75,000
Operations & Maintenance Services @ 30K per yr x 2 yrs	$60,000
Quarterly Groundwater Monitoring @ 8K x 2 yrs	$1,600
Reporting @ 2K x 2 yrs	$4,000
	$140,600

Note: This assumes that groundwater quality objectives may be met in 2 years. Additional O&M, groundwater monitoring and reporting costs may be required until the goals are met.

Project No. L98174	Golden Gate Petroleum	SITE LOCATION MAP FOR OAKLAND CARDLOCK AT 421 23RD AVENUE, OAKLAND, CALIFORNIA	Figure 1
Bonkowski & Associates, Inc.			



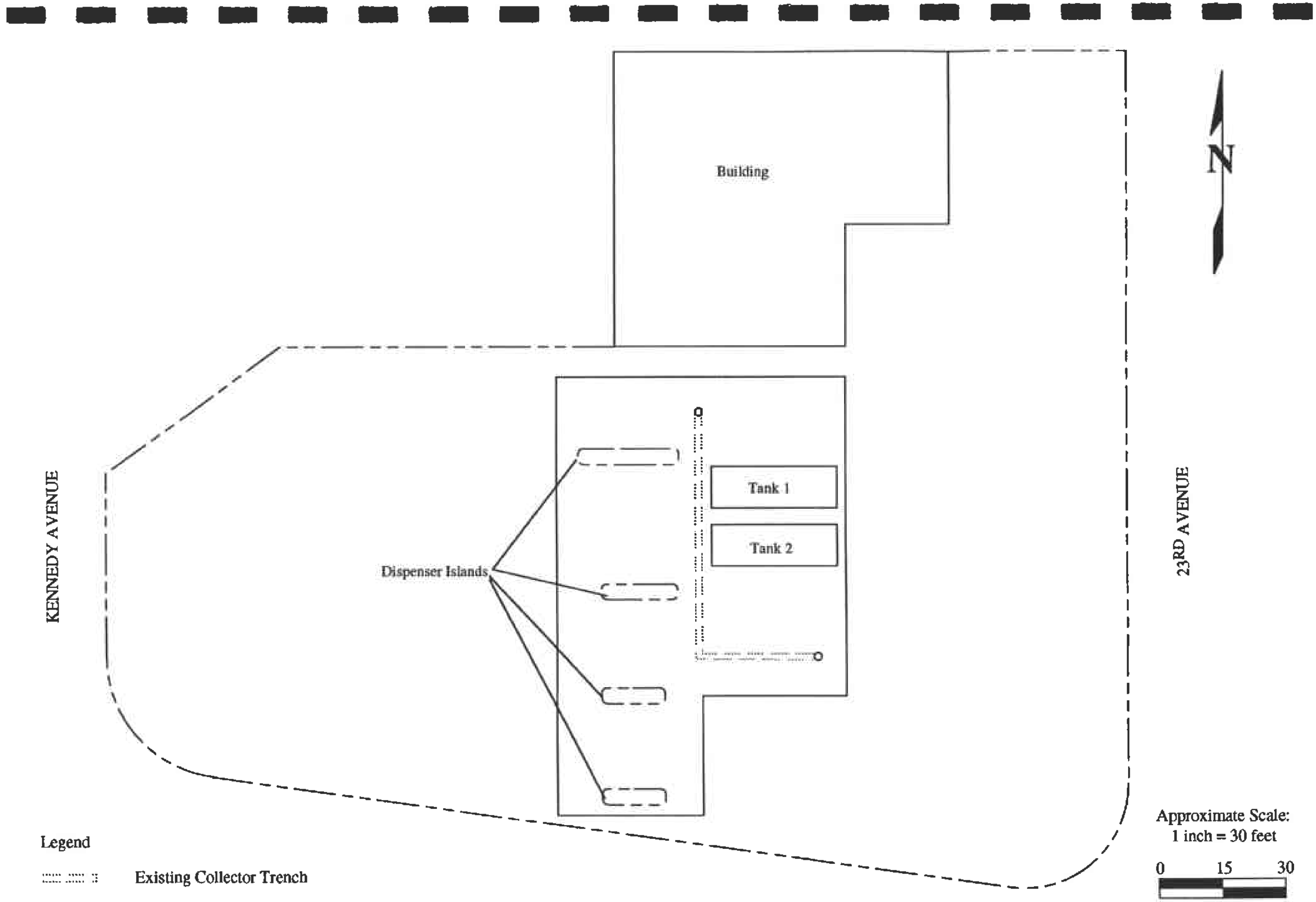
Project No.
L98174

Golden Gate Petroleum

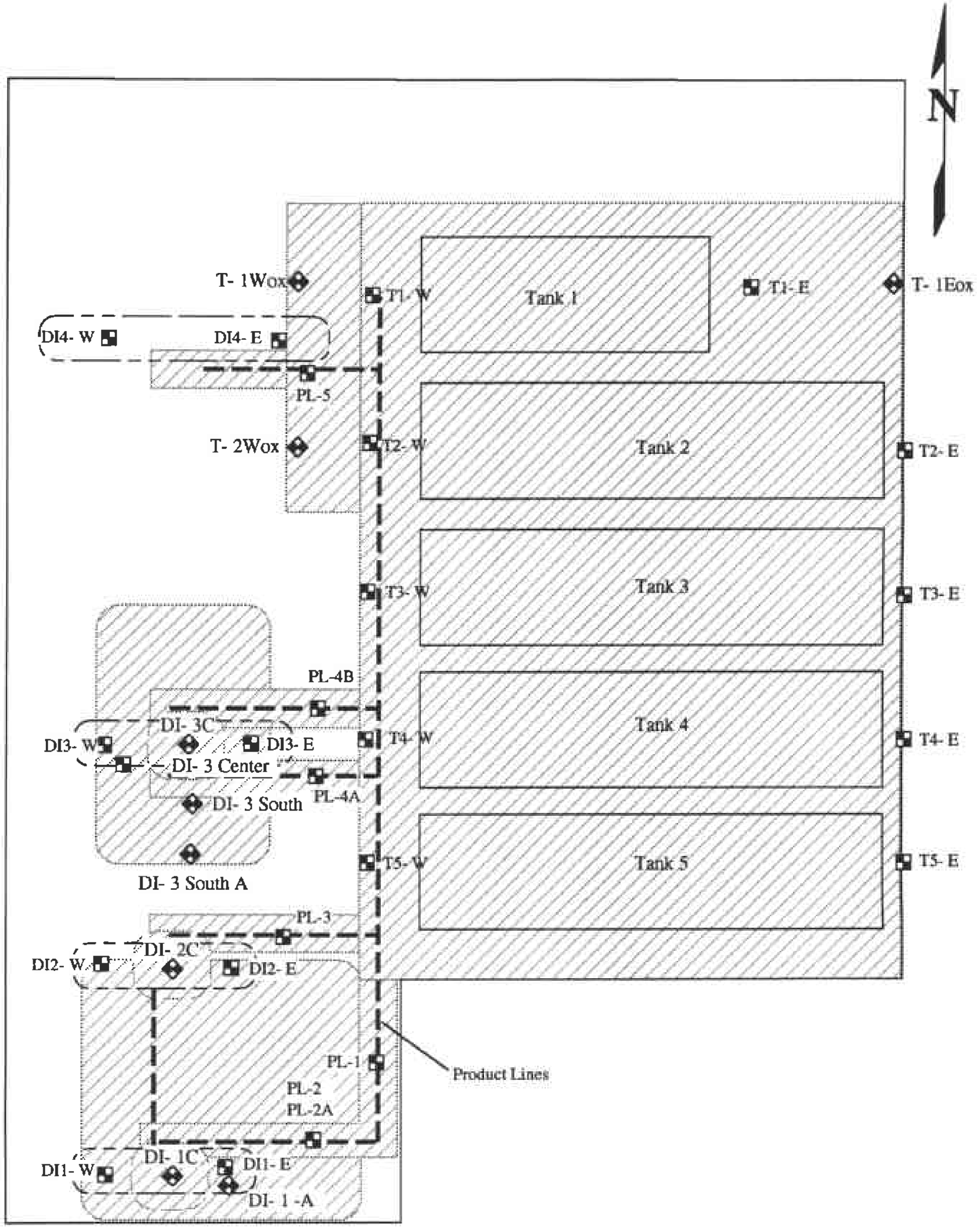
Bonkowski & Associates, Inc.

PREVIOUSLY EXISTING IMPROVEMENTS
421 23rd AVENUE
OAKLAND, CALIFORNIA

Figure
2



Project No. L98174	Golden Gate Petroleum	CURRENT SITE PLAN 421 23rd AVENUE OAKLAND, CALIFORNIA	Figure 3
Bonkowski & Associates, Inc.			



Legend

▨ Extent of Excavation

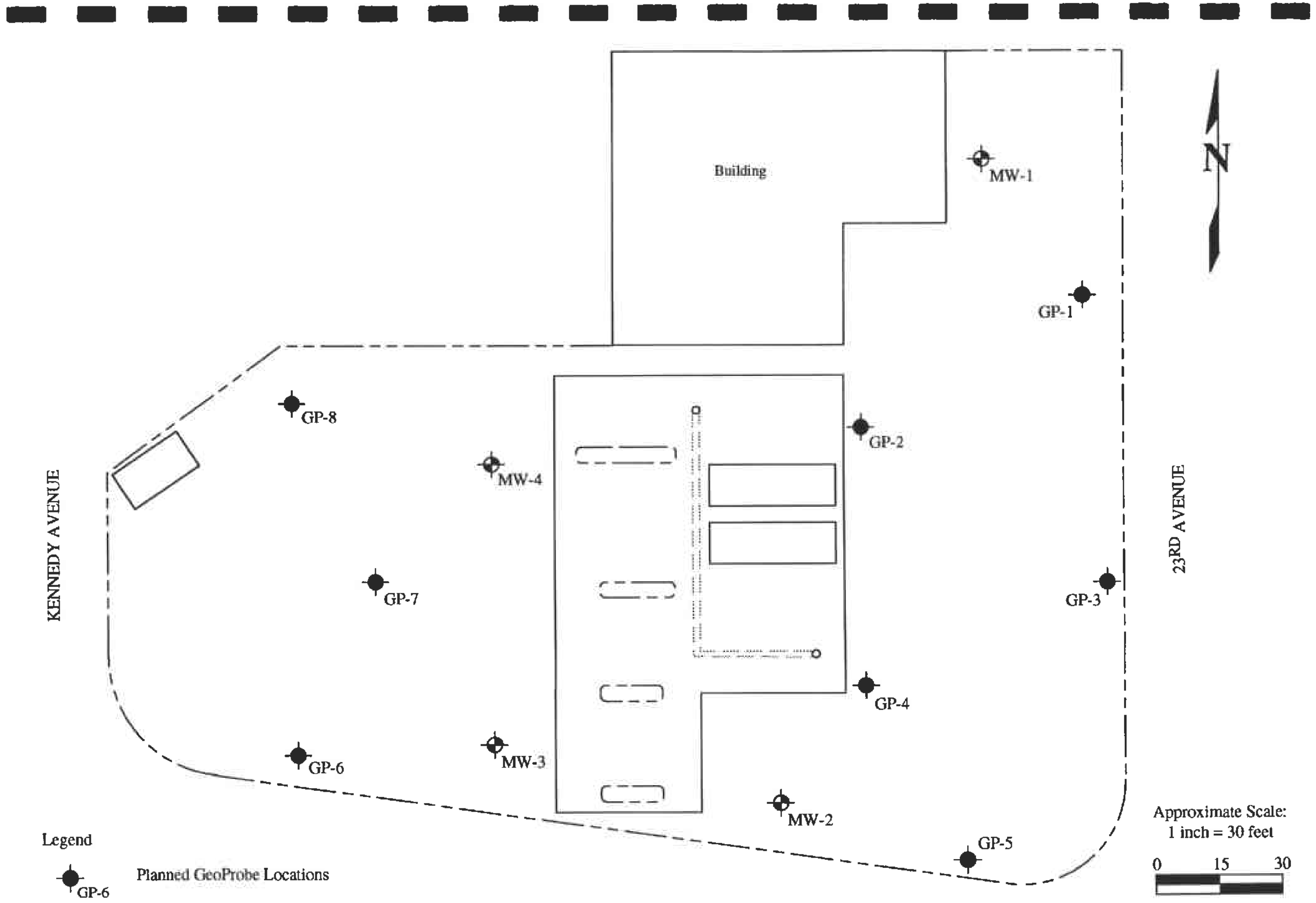
◆ DI- 1C Overexcavation Soil Sample Location

▣ T1- E Soil Sample Location

Approximate Scale:
1 inch = 10 feet

0 5 10

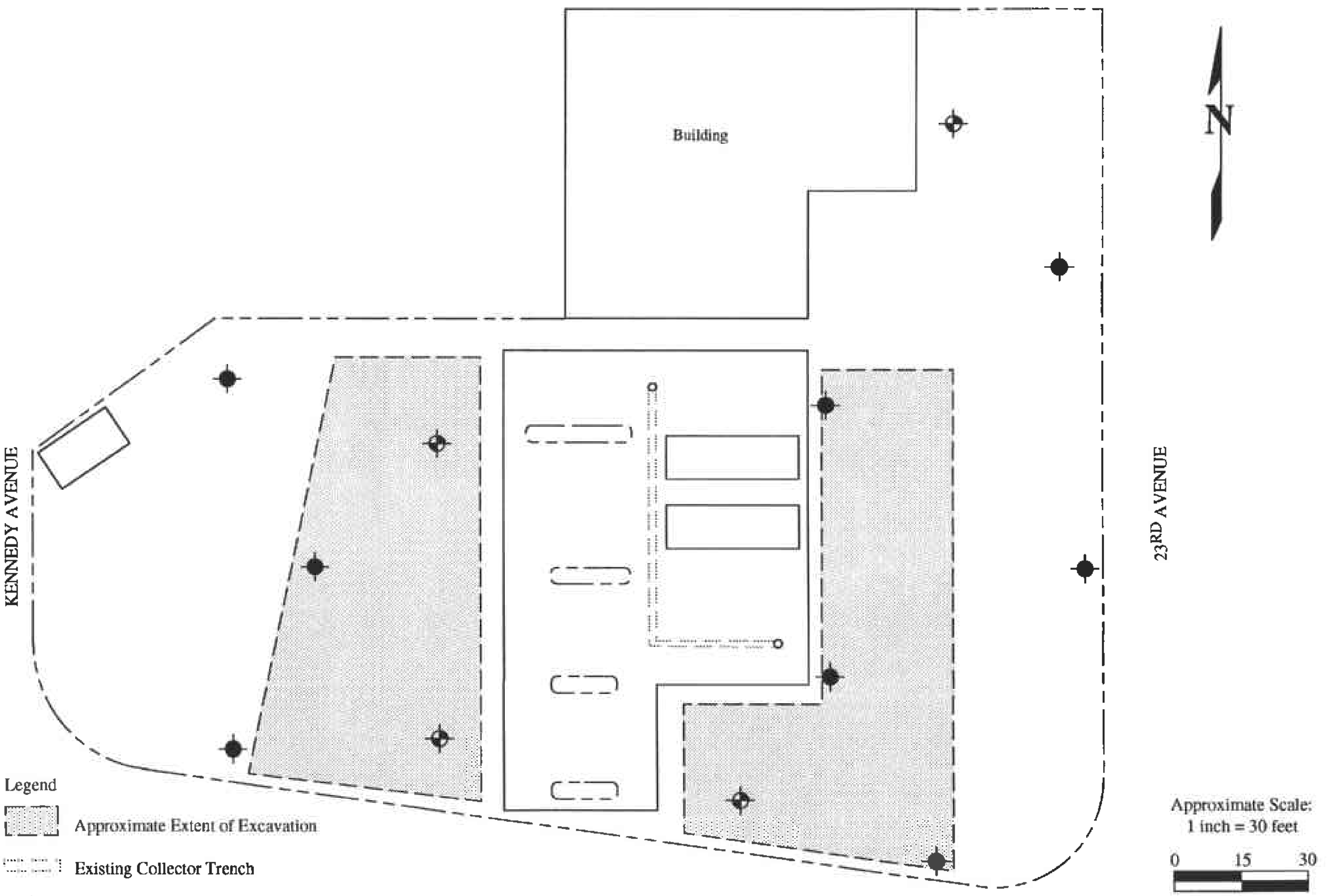
Project No. L98174	Golden Gate Petroleum	EXCAVATION AND SOIL SAMPLE LOCATIONS, 421 23rd AVENUE OAKLAND, CALIFORNIA	Figure 4
Bonkowski & Associates, Inc.			



Legend

● GP-6	Planned GeoProbe Locations
⊕ MW-3	Possible Monitor Well Locations
⁚⁚⁚ ⁚⁚⁚ ⁚	Existing Collector Trench

Project No. L98174	Golden Gate Petroleum	PLANNED GEOPROBE AND POSSIBLE MONITOR WELL LOCATIONS	Figure 5
Bonkowski & Associates, Inc.		421 23rd AVENUE, OAKLAND, CALIFORNIA	



Legend

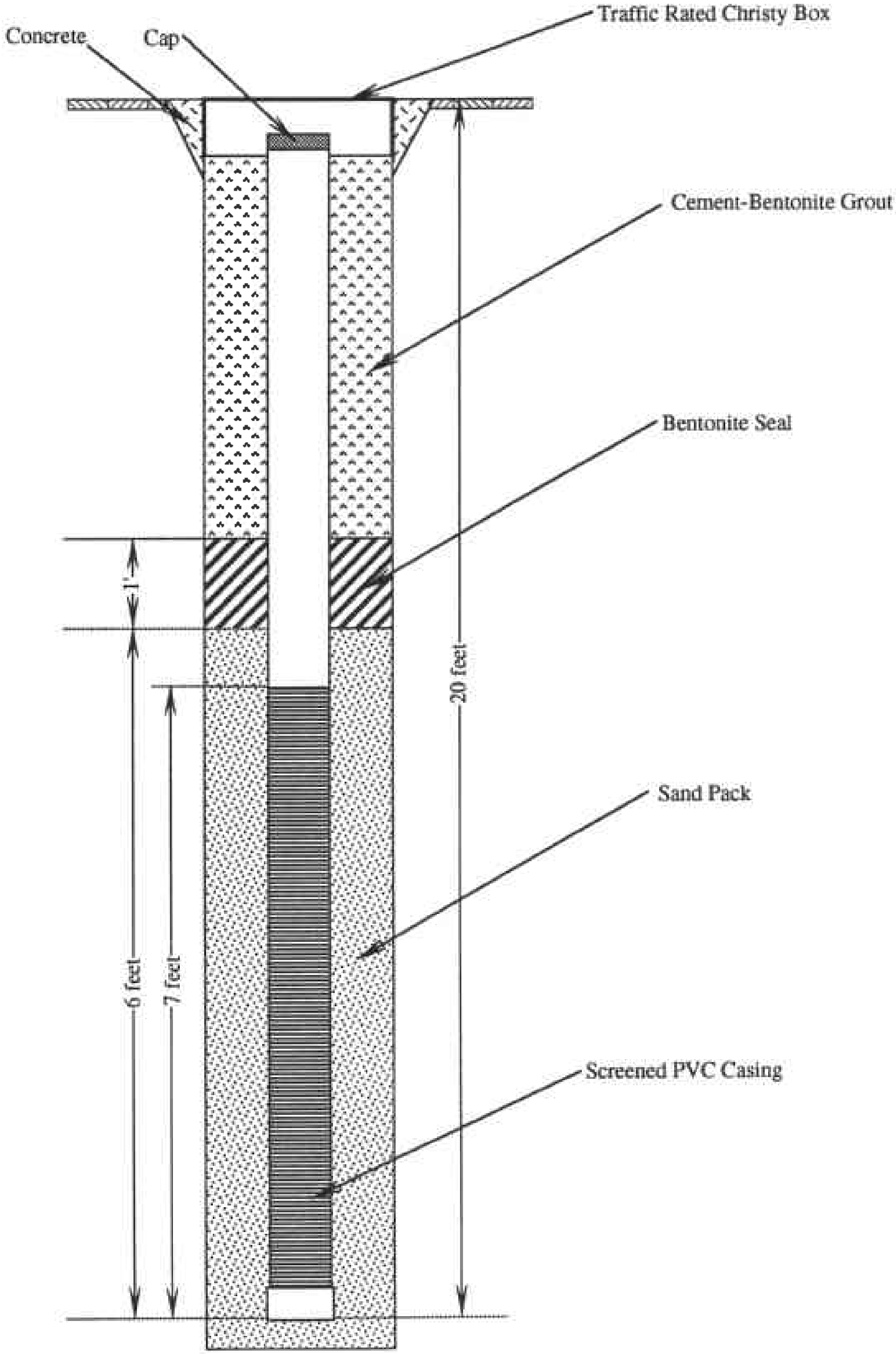
▨ Approximate Extent of Excavation

┄ Existing Collector Trench

● Planned GeoProbe Locations

⊕ Possible Monitor Well Locations

Project No. L98174	Golden Gate Petroleum	EXTENT OF EXCAVATION 421 23rd AVENUE OAKLAND, CALIFORNIA	Figure 6
Bonkowski & Associates, Inc.			



Project No. L93084	Golden Gate Petroleum	PROPOSED MONITOR WELL CONSTRUCTION 421 23rd AVENUE OAKLAND, CALIFORNIA	Figure 8
Bonkowski & Associates, Inc.			

Table A1. Soil Sample Chemical Analyses Results, Golden Gate Petroleum Oakland Cardlock, Oakland California

Sample No.	Sample Location	Sample Depth (feet)	TPHG (mg/kg)	TPHD (mg/kg)	Benzene (µg/kg)	Toluene (µg/kg)	Ethyl-benzene (µg/kg)	Total Xylenes (µg/kg)	MTBE (µg/kg)	Date Sampled
Tank 1	East end	11	3,100	4,400	5,400	3,000	30,000	45,000	2,700	8/13/98
	West end	11	2,000	2,300	15,000	120,000	45,000	240,000	56,000	8/13/98
Tank 2	East end	11	ND	15	ND	ND	ND	ND	850	8/13/98
	West end	11	12,000	9,400	67,000	650,000	240,000	1,400,000	100,000	8/13/98
Tank 3	East end	11	1.4	1.7	ND	ND	ND	ND	1,800	8/13/98
	West end	11	2.6	8.8	34	5.4	36	200	270	8/13/98
Tank 4	East end	11	2.0	2.7	6.1	ND	ND	ND	2,800	8/13/98
	West end	11	1.8	150	ND	ND	8.1	12	7.1	8/13/98
Tank 5	East end	11	ND	ND	ND	ND	ND	ND	20	8/13/98
	West end	11	ND	1.8	ND	ND	ND	ND	ND	8/13/98
SP-N,S,E,W	Soil Pile		70	760	54	74	49	1,800	66	8/13/98
PL-1	Product line	2.5	ND	33	ND	ND	ND	ND	ND	8/14/98
PL-2	Product line	2.5	1,400	20,000	<500	10,000	1,200	5,000	1,200	8/14/98
PL-2A	Product line	2.5	60	670	42	160	<20	360	300	8/14/98
PL-3	Product line	2.5	ND	32	ND	ND	ND	ND	ND	8/14/98
PL-4A	Product line	2.5	ND	ND	ND	ND	ND	ND	ND	8/14/98
PL-4B	Product line	2.5	18,000	<50	60,000	1,800,000	370,000	2,200,000	880,000	8/14/98

Table A1. Soil Sample Chemical Analyses Results, Golden Gate Petroleum Oakland Cardlock, Oakland California

Sample No.	Sample Location	Sample Depth (feet)	TPHG (mg/kg)	TPHD (mg/kg)	Benzene (µg/kg)	Toluene (µg/kg)	Ethyl-benzene (µg/kg)	Total Xylenes (µg/kg)	MTBE (µg/kg)	Date Sampled
PL-5	Product line	2.5	ND	540	ND	ND	ND	ND	8.4	8/14/98
DI-1E	Dispenser Island 1 East end	4	510	8,000	<200	390	<200	2,200	<200	8/14/98
DI-1W	Dispenser Island 1 West end	4	870	22,000	<200	1,400	350	7,600	<200	8/14/98
DI-2E	Dispenser Island 1 East end	4	290	1,900	<50	130	<50	<50	<50	8/14/98
DI-2W	Dispenser Island 1 West end	4	580	9,300	<200	310	<200	<200	<200	8/14/98
DI-3E	Dispenser Island 1 East end	4	680	4,600	<200	430	<200	900	<200	8/14/98
DI-3W	Dispenser Island 1 West end	4	21	31	230	2,000	350	3,400	240	8/14/98
DI-4E	Dispenser Island 1 East end	4	ND	<1.0	6.4	ND	ND	ND	7.9	8/14/98
DI-4W	Dispenser Island 1 West end	4	ND	<1.0	ND	ND	ND	ND	ND	8/14/98

Table A1. **Soil Sample Chemical Analyses Results, Golden Gate Petroleum Oakland Cardlock, Oakland California**

Sample No.	Sample Location	Sample Depth (feet)	TPHG (mg/kg)	TPHD (mg/kg)	Benzene (µg/kg)	Toluene (µg/kg)	Ethyl-benzene (µg/kg)	Total Xylenes (µg/kg)	MTBE (µg/kg)	Date Sampled
T1-Eox	Tank 1 East end over- excavation	11	ND	<1.0	ND	ND	ND	ND	150	8/15/98
T1-Wox	Tank 1 West end over- excavation	11	ND	<1.0	ND	ND	ND	ND	68	8/15/98
T2-Wox	Tank 2 East end over- excavation	11	8.2	<1.0	10	8.2	ND	6.8	7,300	8/15/98
DI-1c	Dispenser Island 1 Center	7	240	1,400	350	900	1,400	2,800	1,700	8/15/98
DI-2c	Dispenser Island 2 Center	8	ND	<1.0	ND	ND	ND	ND	120	8/15/98
DI-3c	Dispenser Island 1 Center	3	87	86	30	120	440	380	130	8/15/98
DI-1-A	Dispenser Island 1 South End	11	20	520	ND	ND	ND	ND	ND	8/20/98
DI-3-South	Dispenser Island 3 South	6	25	140	ND	ND	8.7	110	35	8/20/98
DI-3-South-A	Dispenser Island 3 South	10	ND	1.2	ND	ND	ND	9.4	ND	8/20/98
DI-3-Center-12	Dispenser Island 3-Center	12	30	1,800	<20	95	34	200	1,900	8/20/98

Table A1. **Soil Sample Chemical Analyses Results, Golden Gate Petroleum Oakland Cardlock, Oakland California**

Sample No.	Sample Location	Sample Depth (feet)	TPHG (mg/kg)	TPHD (mg/kg)	Benzene (μg/kg)	Toluene (μg/kg)	Ethyl-benzene (μg/kg)	Total Xylenes (μg/kg)	MTBE (μg/kg)	Date Sampled
Truck 4	Soil Pile		3.4	240	19	ND	ND	ND	240	8/19/98
Truck 8	Soil Pile		23	230	41	ND	ND	240	340	8/19/98
Truck 12	Soil Pile		22	270	39	7.1	ND	56	560	8/19/98
Truck 6B	Soil Pile		3.2	210	ND	ND	ND	34	930	8/20/98
Truck 8B	Soil Pile		5.0	150	6.6	ND	ND	ND	250	8/20/98
Truck 10B	Soil Pile		12	430	12	ND	ND	11	160	8/20/98
Truck 15B	Soil Pile		ND	140	ND	ND	ND	ND	ND	8/20/98
Truck 17B	Soil Pile		60	450	56	96	ND	88	69	8/20/98
Truck 19B	Soil Pile		94	750	87	110	ND	140	ND	8/20/98
Truck 25B	Soil Pile		ND	57	ND	ND	ND	ND	ND	8/20/98
Truck 27B	Soil Pile		99	770	<50	80	<50	<50	<50	8/20/98
Truck 29B	Soil Pile		100	460	<50	80	<50	60	<50	8/20/98

Table A2. Groundwater Sample Chemical Analyses Results, Petroleum Fuel Hydrocarbons, Golden Gate Petroleum Cardlock, Oakland, California.

Sample Number	Sample Locaton	TPHG (mg/l)	TPHD (mg/l)	Benzene (µg/l)	Toluene (µg/l)	Ethyl-benzene (µg/l)	Total Xylenes (µg/l)	MTBE (8020) (µg/l)	Lead (200.7) (µg/l)	Date Sampled
Pit	Tank Cavity	43	12	<25	<25	<25	<25	49,000		8/13/98
ST-A	Storage Tank A	0.12	<0.05	<0.50	<0.50	<0.50	<0.50	5,600		9/1/98
ST-B	Storage Tank B	<0.05	<0.05	<0.50	<0.50	<0.50	<0.50	1,700		9/1/98
Effluent	Discharge from Storage Tank A	--	--	<0.50	<0.50	<0.50	<0.50	--	26	9/22/98
State MCL		0.005[1]	0.100[2]	1.0[3]	42[2]	29[2]	17[2]	14[4]		

1 -- Taste and odor threshold (SWRCB)

2 -- Taste and odor threshold (U.S. EPA)

3 -- California Primary MCL

4 -- Proposed public health goal (OEHHA)

Table A3. Groundwater Sample Chemical Test (EPA 8260 and Total Lead) Results Golden Gate Petroleum Cardlock Oakland, California

Sample No. **Sample Location**	**West** **Collector Trench** **West Access**
Units **Analyte**	**(µg/l)**
Benzene	11
Bromobenzene	ND
Bromochloromethane	ND
Bromodichloromethane	ND
Bromoform	ND
Bromomethane	ND
t-Butanol	ND
n-Butylbenzene	ND
Sec-butylbenzene	ND
Tert-butylbenzene	ND
Carbon Tetrachloride	ND
Chlorobenzene	ND
Chloroethane	ND
Chloroform	ND
Chloromethane	ND
2-Chlorotoluene	ND
4-Chlorotoluene	ND
Dibromochloromethane	ND
1,2-Dibromo-3-chloropropane	ND
1,2-Dibromoethane	ND
Dibromomethane	ND
1,2-Dichlorobenzene	ND
1,3-Dichlorobenzene	ND
1,4-Dichlorobenzene	ND
Dichlorodifluoromethane	ND
1,1-Dichloroethane	ND
1,2-Dichloroethane	ND
1,1-Dichloroethene	ND
Cis-1,2-Dichloroethene	ND
Trans-1,2-Dichloroethene	ND
1,2-Dichloropropane	ND
1,3-Dichloropropane	ND
2,2-Dichloropropane	ND
1,1-Dichloropropene	ND
Cis-1,3-Dichloropropene	ND
Trans-1,3-Dichloropropene	ND

Table A3. Groundwater Sample Chemical Test (EPA 8260 and Total Lead) Results Golden Gate Petroleum Cardlock Oakland, California

Sample No. Sample Location	West Collector Trench West Access
Units Analyte	(µg/l)
Di-isopropyl Ether	ND
Ethanol	ND
Ethylbenzene	ND
Ethyl Tertiary Butyl Ether	ND
Hexachlorobutadiene	ND
Isopropylbenzene	ND
p-Isopropyltoluene	ND
Methylene Chloride	ND
Methyl Tertiary Butyl Ether	4,500
Naphthalene	ND
N-Propylbenzene	ND
Styrene	ND
Tertiary Amyl Methyl Ether	98
Tertiary Butyl Alcohol	ND
1,1,1,2-Tetrachloroethane	ND
1,1,2,2-Tetrachloroethane	ND
Tetrachloroethene	ND
Toluene	ND
1,2,3-Trichlorobenzene	ND
1,2,4-Trichlrorbenzene	ND
1,1,1-Trichloroethane	ND
1,1,2-Trichloroethane	ND
Trichloroethene	ND
Trichlorofluoromethane	ND
1,2,3-Trichloropropane	ND
1,2,4-Trimethylbenzene	ND
1,3,5-Trimethylbenzene	ND
Vinyl Chloride	ND
Total xylene	ND
Total Lead	ND
Date Sampled	11/2/98

VIII. MAMMALIAN TOXICOLOGY

Although the frequency of occurrence has been low, MAHs have been detected in California's ground water (see Chapter V: Monitoring). To determine whether these findings indicate a hazard to human and/or domestic animal health, it is necessary to understand the toxicological properties of the MAHs. These include the adverse effects which can be evoked by MAHs, as well as the exposure levels required to elicit these detrimental responses.

Many reviews of MAH mammalian toxicology, particularly benzene, have recently been performed. Furthermore, DHS has primary responsibility for protection of human health. The objective of this section is to briefly summarize from these reviews the major toxicological properties attributed to MAHs. There are many reports based on occupational exposure to a mixture of organic solvents. Although these data are informative, it is difficult to designate any individual chemical in the mixture as being primarily responsible for adverse effects. This type of work will not be reviewed here.

The route of exposure for a majority of the toxicological studies on MAHs has been inhalation. Studies where MAHs were administered by oral ingestion via water or food are infrequent, but suggest that MAHs can be rapidly absorbed across the intestinal tract (U.S. EPA, 1987a, b, c, d). These aromatics are promptly transformed metabolically and conjugated primarily to a hippuric acid; the conjugates are readily excreted in urine. MAHs are generally cleared from the body within 12 to 24 hours. This scheme applies to benzene, toluene, xylenes, and ethylbenzene, with the exception that the major metabolites of ethylbenzene are mandelic acid and phenylglyoxylic acid.

Essentially all of the information presented in this section was derived from review articles (i.e., critical evaluation of original research papers was not the objective).

Acute Toxicity

Median lethal dose (LD_{50}) values are included here to give some indication of MAH acute toxicity.

Oral LD_{50} Values in Rats

Benzene	: 3.0 to 4.9 g/Kg
Toluene	: 5.3 to 7.5 g/Kg
Ethylbenzene	: 3.5 to 5.5 g/Kg
Xylenes	: 4.3 to 5.0 g/Kg

These data suggest that MAHs do not constitute a serious acute lethality threat to mammals. Compared to other priority pollutants, MAHs are considered slightly to moderately toxic. The following sections describe epidemiological and experimental observations on toxic effects of MAHs on humans and other mammals.

Toluene

Observations in Humans

Data presented in this section were taken from several review documents (U.S. EPA, 1980d, 1983a, 1985c, 1987c; NRC, 1981, 1985; Dangerous Properties of Industrial Materials Report, 1985; Fishbein, 1985a; Haley, 1987). Most of the data on effects of toluene on humans come from occupational exposures or from solvent abuse (i.e., "glue sniffing"). In solvent abuse, exposures are short-term and to extremely high levels of the solvent. Toluene is a common glue solvent, and abuse has been associated with neurological (especially central nervous system - CNS) problems. Other adverse effects attributed to solvent abuse include liver and kidney damage, hematological dysfunctions, and cardiac arrhythmias. N-hexane is also a common glue solvent to which neuropathies have been attributed, and evidence is not sufficient to separate toluene as the specific cause of the adverse effects, especially the hematological dysfunctions.

Animal studies with toluene have not clarified the neurotoxic potential of this chemical. Restoration of neurological, hepatic, and renal functions are normally observed when exposure is terminated. In some cases, prolonged exposure to toluene led to residual CNS effects. The levels of toluene found in surface water, ground water, and finished drinking water are many orders of magnitude less than those experienced in solvent abuse.

A large body of data on occupational exposure to solvent vapors exists. Interpretation of these data is difficult, since exposure is usually to a mixture of organic solvents; actual exposure levels and duration of exposure are seldom clear. Several health problems (e.g., hematological, immunologic, liver, renal, menstrual, and neurological) have been observed in workers exposed to solvent vapors. In cases of occupational exposure to toluene alone hematological problems have not been noted.

Chronic exposures to toluene vapors have been associated most commonly with neurologic and neuromuscular toxicity (e.g., impairment of mental and emotional perception, speech patterns, mental capabilities such as learning, neuromuscular coordination, and reflexes). The no-observable-adverse-effect-level (NOAEL) for inhaled toluene on these neurological and other dysfunctions appears to be approximately 377 mg/m^3 (i.e., 100 ppm). Impairment of hepatorenal functions have been connected to occupational inhalation of toluene. With a cessation of exposure, restoration of normal hepatorenal and neurological functions generally are seen. Confirmation of abnormal liver or renal function as a result of toluene exposure is lacking. No connections have been made between chronic exposures to toluene vapors and teratogenic or carcinogenic effects in humans. Teratogenic potential, however, has not been fully clarified.

The National Institute for Occupational Safety and Health (NIOSH) has recommended a ten-hour time-weighted-average (TWA) of 100 ppm as an inhalation exposure limit for toluene; a ceiling of 200 ppm for a 10-minute sampling period is part of the recommendation. Persons exposed occupationally to toluene may be at increased health risks. The OSHA enforceable standard for occupational exposure to toluene is 200 ppm. For other segments of the population, toluene exposures are such that they are not likely to be associated with significant hazard. Exposure through water appears to be particularly insignificant.

Observations in Other Mammals

Inhalation is the exposure route in a majority of reported animal toxicity studies with toluene. Most of the earlier investigations were flawed in that the toluene used was contaminated with benzene or other solvents; many of the reports fail to mention purity of the toluene utilized. Adverse effects attributed to toluene in mammalian studies are presented in Table VIII-1. These data suggest that toxicological effects of toluene occur in the high milligram or gram per cubic meter range. The most pronounced effects of toluene are on the CNS. Adverse impacts on the kidney have not been convincingly demonstrated. As in humans, hematopoietic tissue is not considered to be a target tissue for toluene.

Using a variety of assay methods, toluene has not been demonstrated to be mutagenic nor genotoxic. Exposure of rats by inhalation to toluene at levels up to 300 ppm for 24 months did not produce an increased incidence of neoplastic, proliferative, inflammatory, or degenerative lesions. An increased incidence of malignant tumors in rats given 500 mg toluene/kg/day by oral gavage for 104 weeks has been reported (Maltoni et al., 1985). Maltoni's results with both toluene and xylene (see below) are inconsistent with other data. This study requires validation since the purity of the MAHs was not reported and experiments with benzene were conducted simultaneously.

Other studies in which no deleterious effects of toluene were reported are summarized in Table VIII-2. The data presented in this table indicate that rats can endure exposure to toluene in the high milligram per kilogram body weight range without permanent adverse effects. These data appear to contradict some effects noted in Table VIII-1. These variations could be due to any of several factors, including purity of toluene, strain or species of test subject, method of generating toluene vapor, or duration of exposure.

Mammalian studies with toluene support the conclusion from observations on human exposure: Given the low levels of toluene detected in California's sources of drinking water (see Chapter V: Monitoring) human health does not currently appear to be at significant risk from this chemical.

TABLE VIII - 1.

Toxicogical Effects Of Toluene (Data compiled from the review articles referenced in text).

Species	Route of Exposure	Duration of Exposure	Highest Dose Without Effect	Parameters Monitored
Rat	Oral	Single dose	1.7 g/kg	Lowest acute dose for CNS inhibition.
Rat	Inhalation	1 hr/day, 5 days/ wk, 6 wk	2260 mg/m^3	Histological changes in kidney.
Rat	Inhalation	6 hr/day, 5 days/ wk, 24 months	377 mg/m^3	Decreased hematocrit.
Rat	Inhalation	2 hr/day, 60 days	15 g/m^3	CNS impairment.
Rat	Inhalation	14 hr/day, 7 days/ wk, 14 wk	5280 mg/m^3 (99% pure toluene)	Decreased body weight gain.
Rat	Inhalation	14 hr/day, 7 days/ wk, 14 wk	3390 and 5280 mg/m^3 (99% pure toluene)	Reduction of motor neuron activity during weeks 2 to 8, but with recovery.
Rat (female)	Inhalation	6 hr/day, 5 days/ wk, 6 months	265 ppm	Growth inhibition.
Rat degeneration (female)	Inhalation	8 hr/day, 6 days/ wk, 1 year	100 ppm	Decreased testicular weight; of germinal epithelium at 200 ppm.
Rat (female)	Inhalation	8 hr/day, days 1 to 21 of gestation	1000 mg/m^3	Retarded skeletal development in embryos.

(Continued)

TABLE VIII - 1 (Continued)

Species	Route of Exposure	Duration of Exposure	Effect Level	Effect
Rat (female)	Inhalation	24 hr/day, days 7 to 14 of gestation	1000 mg/m^3	Skeletal growth retardation in embryos, but no teratogenic effects.
Mouse (female)	Inhalation	24 hrs/day, days 6 to 13 of gestation	500 mg/m^3	Low fetal weights, but no teratogenic effects.

Ethylbenzene

Observations in Humans

This section is a summary of data reviewed in several documents (U.S. EPA, 1980c, 1985b, 1987b; NRC, 1981, 1985; Fishbein, 1985b; Dangerous Properties of Industrial Materials Reports, 1987). Occupational exposures to the solvent ethylbenzene are not uncommon. This monocyclic is generally found in solvent mixtures, where health problems resulting from exposure cannot be conclusively associated with any one of the chemicals. Epidemiological studies relating to ethylbenzene exposure have not been located. The inhalation NOAEL for ethylbenzene has been set at 100 ppm (435 mg/m^3, OSHA standard).

Observations in Other Mammals

In studies with experimental animals, the CNS, liver, and kidney are the tissues most frequently cited as targets for toxic effects of ethylbenzene. Some deleterious responses have been noted in studies where animals were exposed to xylenes contaminated with ethylbenzene (see "xylenes" below). It is impossible to isolate ethylbenzene as the toxic agent in such studies.

In rats orally gavaged once per day, five days per week for six months with 408 mg ethylbenzene/kg/day, histopathological changes were seen in kidney and liver. There were no apparent effects on hematopoietic tissues. No adverse effects were seen in this study when the rats were dosed with 136 mg/kg/day. In rhesus monkeys exposed by inhalation to 600 ppm ethylbenzene four hours per day, five days a week for 186 days, there were some indications of testicular degeneration and liver hypertrophy. No effects were seen at 400 ppm in monkeys, rabbits, or guinea pigs.

In inhalation studies with rabbits, guinea pigs, and rats, the test organisms were exposed to ethylbenzene for 7 to 8 hours per day, five days per week for 214 days. The NOAEL in this study was 200 ppm. Slight changes in kidney and liver were noted at 400 ppm. Neither embryotoxicity nor teratogenicity was reported in rabbits inhaling 4,348 mg ethylbenzene/m^3 for 6 to 7 hours per

TABLE VIII - 2

Toxicological Studies In Which Toluene Produced No Significant Effects
(Sources of information the same as cited in text).

Species	Route of Exposure	Duration of Exposure	Highest Dose Without Effect	Parameters Monitored
Rat	Inhalation	6 hr/day, 5 days/wk, 26 wk	5650 mg/m^3	No significant changes in tissue histology, blood chemistry, or urine.
Rat, Dog	Inhalation	6 hr/day, 13 wk	3900 mg/m^3	No significant changes in hematology or blood chemistry.
Rat	Inhalation	6 hr/day, 5 days/wk, 24 months	300 ppm (99.98% pure toluene)	No significant changes in tissue histology, hematology, blood chemistry, or tumor incidence.
Rat	Inhalation	8 hr/day, 32 wk	2000 ppm (99.9% pure toluene)	No significant hematology changes.
Rat	Inhalation	6 hr/day, 5 days/wk, 90 days	1000 ppm (99.98% pure toluene)	No significant changes in tissue histology hematology, blood chemistry, or urine.
Rat	Oral	5 days/wk, 6 months	590 mg/kg/day	No significant changes in tissue histology, hematology, or blood chemistry.
Rat, Guinea Pig Dog, Monkey	Inhalation	8 hr/day, 5 days/wk, 6 wk	4095 mg/m^3	No significant changes in tissue histology or hematology.
Rat (female)	Inhalation	6 hr/day, days 6 to 15 of gestation	1377 mg/m^3	No embryotoxic or teratogenic effects.
Mouse (female)	Inhalation	6 hr/day, days 1 to 17 of gestation	1000 ppm	No embryotoxic or teratogenic effects.

day on days one through 24 of gestation; no effects were seen in rats exposed to the same level on days one through 19 of pregnancy. Ethylbenzene has not shown mutagenic activity in an array of test systems.

The ethylbenzene toxicology database is inadequate. The few data which exist indicate that the adverse effect levels are relatively high.

Xylenes

Observations in Humans

Data included in this section were derived from several review documents (NRC, 1981, 1985; Von Berg, 1982; Dangerous Properties of Industrial Materials Reports, 1984a, b, 1986; U.S. EPA 1985d, 1987d; Fishbein, 1985c; Haley, 1986). The lowest oral lethal dose for xylenes is considered to be 50 mg/kg body weight. Inhalation is considered the most probable route of exposure. As with other MAHs, the xylene isomers are neurotoxins, but relatively high doses are required to provoke CNS or neuromuscular disturbances. The OSHA inhalation standard for xylene is 100 ppm (435 mg/m^3). NIOSH recommends adherence to this standard as a time-weighted average for up to a 10-hour workday, 40-hour workweek. A maximum concentration of 200 ppm (not to be exceeded by a 10 minute sampling period) has also been proposed by NIOSH.

Epidemiological studies related to xylene have been few, and small in terms of exposed population. Because these studies involved mixtures of chemicals, effects have not been identified specifically for xylenes.

Observation in Other Mammals

Inhalation has been the avenue of xylene exposure in most studies with experimental animals. Liver, CNS, and kidney have been most commonly identified as target tissues for adverse effects. Deleterious effects ascribed to xylene are summarized in Table VIII-3. The significance of these data is difficult to assess due to contamination of the xylene with other solvents, especially ethylbenzene. In feeding studies, adverse effects do not generally occur until xylene intake is above 100 mg/Kg/day. Maltoni and

Table VIII - 3

Toxicological Effects Of Xylenes. (Data compiled from review articles cited in text).

Species	Route of Exposure	Duration of Exposure	Effect level	Effect
Rat	Oral (In diet)	Six months	200 mg/kg (o-xylene)	Ultrastructural changes in hepatocytes.
Rat	Inhalation	8 hr/day, 7 days/wk, 1 year	4750 mg/m^3	Ultrastructural changes in liver.
Rat	Inhalation	6 hr/day, 131 days	250 ppm	Lower mating indices.
Rat	Inhalation	24 hr/day, days 7 to 14 of gestation	1500 mg/m^3	Lower fetal weights with o-xylene, but not with m- or p-xylene.
Rat	Inhalation	24 hr/ day, days 7 to 14 of gestation	1500 mg/m^3	Retarded skeletal development with p-xylene, but not with m- or o-xylene.
Rat	Inhalation	6 hr/day, days 6 to 15 of gestation	1730 mg/m^3	Abnormalities in embryo skeletal development.
Rat	Inhalation	24 hr/day, days 9 to 14 of gestation	1000 mg/m^3	Abnormalities in embryo skeletal development.
Mouse	Oral	Days 6 to 15 of gestation	2.4 ml/kg/day (xylene containing 17% ethylbenzene)	Developmental abnormalities in fetuses.

colleagues (1985) reported an increased occurrence of malignant tumors in rats treated with 500 mg xylene/kg/day by oral gavage for 104 weeks. Because most of the available literature indicates that xylene is not carcinogenic, this result should be confirmed to ensure that contamination with benzene (which was being used in concurrent tests) did not occur.

Testing for mutagenicity is complicated by ethylbenzene contamination of most xylenes. Generally, however, xylene has been shown to be nonmutagenic. Studies in which xylenes did not show detrimental effects are presented in Table VIII-4. Xylenes may not be teratogenic at levels which do not cause maternal toxicity. However, one study suggests that xylene inhibits skeletal development in fetuses (Table VIII-3).

Benzene

Observations in Humans

The discussion of benzene will be particularly abbreviated since the toxicology database has been extensively reviewed elsewhere (e.g., U.S. EPA, 1980a, 1982a, 1985a, 1987a; ECETOC, 1984; Snyder, 1984; Fed. Register 50, No. 237:50512-50578, 1985; Fishbein, 1984; NRC, 1985; NTP, 1986; ATSDR, 1987; Cronkite, 1987; Kalf et al., 1987; Marcus, 1987). The reader is referred to these documents for detailed analysis of the literature. Although other toxic effects have been attributed to benzene, this MAH is most commonly known as a hematotoxin and carcinogen. Evidence is accumulating which also associates benzene with immune system dysfunction.

Chronic exposure to benzene can cause alterations in hematopoietic tissue. Lymphoid tissues and myeloid bone marrow are affected, resulting in pancytopenia (decreases of leukocytes, erythrocytes, and thrombocytes in circulating blood). In mild cases of benzene hematotoxicity, a decrease in only one of these elements may be seen (e.g., leukopenia, anemia, or thrombocytopenia). Prolonged exposure to benzene can result in aplastic anemia and/or a deterioration of immunological defense mechanisms. These adverse effects can occur with exposure to 10 ppm benzene in inhaled air. Benzene, at levels less than 10 ppm, is also capable of producing chromosomal aberrations in human cells.

TABLE VIII - 4.

Toxicological Studies In Which Xylene Produced No Significant Adverse Effects (Sources of information the same as cited in text).

Species	Route of Exposure	Duration of Exposure	Highest Dose Without Effect	Parameters Monitored
Rat, Dog, Guinea Pig, and Monkey	Inhalation	Continuous for 90 days	337 mg/m^3 (o-xylene)	No significant changes in tissue histology or hematology.
Rat	Inhalation	6 hr/day, 5 days/wk, 13 wk	2000 mg/m^3	No significant changes in tissue histology, hematology, or blood chemistry.
Rat, Rabbit	Inhalation	8 hr/day, 6 days/wk, 130 days	690 ppm	No significant deviations from normal in peripheral blood.
Rat, Mouse	Oral	Two years	500 mg/kg/day (Rat) 1000 mg/kg/day (Mouse)	Noncarcinogenic
Rat	Inhalation	24 hrs/day, days 7 to 14 of gestation	1500 mg/m^3	Nonteratogenic (All xylene isomers tested separately).
Rat	Inhalation	24 hrs/day, days 9 to 14 of gestation	1000 mg/m^3	Nonteratogenic

The International Agency for Research on Cancer (IARC) concluded that there is sufficient evidence to identify benzene as a human carcinogen (IARC, 1982). Case reports and epidemiological studies have associated benzene with acute and chronic myelogenous leukemia, lymphatic tissue carcinomas, and other hematopoietic tissue carcinomas. A risk assessment for benzene estimated that if 1,000 workers were exposed to benzene at 100 ppm for a working lifetime, 170 of the workers would develop leukemia. It has also been predicted that exposure for approximately one year to 10 ppm benzene will increase the risk of cancer 560-fold. EPA's Office of Drinking Water has estimated that 0.7 ug of benzene per liter of drinking water over a lifetime increases the risk of cancer by one case in every million persons.

Controversy remains about the duration and level of exposure to benzene required to induce cancer. Some researchers have argued that exposure by inhalation to concentrations as low as two ppm may induce leukemia, whereas others contend that no adequate epidemiological studies have associated benzene exposure with cancer at concentrations below 150 ppm. The current Federal inhalation standard for benzene is one ppm for an eight-hour time-weighted average, with five ppm as the maximum peak for a duration not to exceed 15 minutes.

Observations in Other Mammals

Data also reveal that benzene is a hematotoxin and immunosuppressant in rodents (Table VIII-5); bone marrow and lymphoid tissue appear to be affected. Leukopenia is observed at relatively low exposure levels; the leukopenia NOEL in rats seems to be between 1 to 5 mg/kg/day. In mice and rats, decreased bone marrow cellularity, leukocytopenia, and lymphocytopenia have been reported within two weeks of exposure to benzene vapors at 25 ppm and below. Several investigators contend that leukopenia is an early stage of depression of hematopoietic tissue. Hematopoietic suppression may predispose to leukemia or be a stage in a sequence leading to leukemia. There is sufficient evidence that benzene is carcinogenic in experimental animals (NTP, 1985, 1986). Although benzene has been shown to be fetotoxic, this effect generally is not seen independent of maternal toxicity. Benzene has not been shown to be teratogenic.

TABLE VIII - 5

Toxicological Effects Of Benzene (Data compiled from references listed in text)

Species	Route of Exposure	Duration of Exposure	Effect Level	Effect
Mouse	Inhalation	6 hr/day, 5 days/ wk, 178 days	10 ppm	Depression in number of splenic red blood cells, circulating red blood cells, circulating lymphocytes, and immunocompetence.
Mouse	Oral, in water	7 days/wk, 4 wk.	8 mg/kg/day	Immunotoxic - decreased number of erythaytes, leukoytes, and eymphocytes in peripheral circulation.
Mouse	Oral	5 days/wk, 103 wk	25 mg/kg/day	Bone marrow hyperplasia, increased incidence of malignant lymphomas.
Mouse	Oral	5 days/wk, 103 wk	50 mg/kg/day	Increased incidence of Zymbal gland, alveolar/bronchiolar, and mammary gland carcinomas.
Mouse	Oral	5 days/wk, 103 wk	100 mg/kg/day	Increased incidence of hepatocellular carcinomas.
Rat	Oral	5 days/wk, 103 wk	25 mg/kg/day	Lymphoid depletion in spleen, increased incidence of Zymbal gland and oral cavity carcinomas.
Rat (male only)	Oral	4-5 days/wk, 52 wk	250 mg/kg/day	Increased incidence of leukemias, mammary gland, and Zymbal gland carcinomas.
Rat	Inhalation	1.5 year	100 ppm	Increased incidence of neoplasms.
Mouse	Inhalation	6 hr/day, 5 days/	300 ppm	Increased incidence of hematopoietic tissue neoplasms, bone marrow hyperplasia, and spleen hyperplasia.
Mouse	Inhalation	6 hr/day, 5 days/ wk, 90 days	300 ppm	Bone marrow, testicular, and ovarian
Rat	Inhalation	6 hr/day, 5 days/ wk, 90 days	300 ppm	Anemia, leukopenia, decreased cellularity in bone marrow.
Rat	Oral	132 days	10 mg/kg/day	Leukopenia
Rat	Inhalation	6 hr/day 4 days/ wk, 31 wk	95 mg/m3 (=8mg/kg/day)	Leukopenia

In several different mammalian species, benzene has been shown to cause chromosomal aberrations; this response has been demonstrated in vivo, when exposure is by oral gavage or by inhalation, as well as when cells are exposed in vitro with metabolic activation. In all systems, male animals and cells tend to be more sensitive to the clastogenic effects of benzene. Other forms of genotoxicity also have been reported. In both humans and other mammals, it is believed that a metabolite, rather than benzene itself, is the genotoxic and hematotoxic agent.

Conclusions

Available data demonstrate convincingly that benzene is a hematotoxin and a carcinogen in both humans and other mammals. On the basis of nonthreshold models of carcinogenicity, criteria and standards for drinking water, ground water, and ambient water are set at very low levels. EPA has set the Maximum Contaminant Level (MCL) for drinking water at five ug/l and CDHS has recommended a drinking water action level of 0.7 ug/l.

Detection of benzene in drinking water or ground water has been infrequent in California. Nonetheless, some positive identifications have been above CDHS's action level. Of the MAHs which may potentially contaminate drinking water or ground water, benzene may pose the most serious threat to human health.

None of the MAHs have a high degree of acute toxicity. Toluene, ethylbenzene, and xylene have been shown to have toxic impacts on the CNS, liver, and kidney. CNS dysfunction is the health effect of primary concern. However, the threshold concentrations for these adverse effects are relatively high. The levels of these three MAHs required for inducing deleterious effects are much greater than those which have been detected in California's surface water, ground water, or drinking water. For reference, the average daily exposure of humans, by inhalation, to the total of benzene, toluene, ethylbenzene, and the xylenes in Los Angeles and Oakland during 1979 was estimated at 2,296 mg per day and 645 mg per day, respectively (Singh et al., 1981). Moreover, humans are much more likely to be exposed to MAHs in air than in drinking water.